THE MARVELS AND MYSTERIES OF SCIENCE

BY

ELLISON HAWKS, F.R.A.S.

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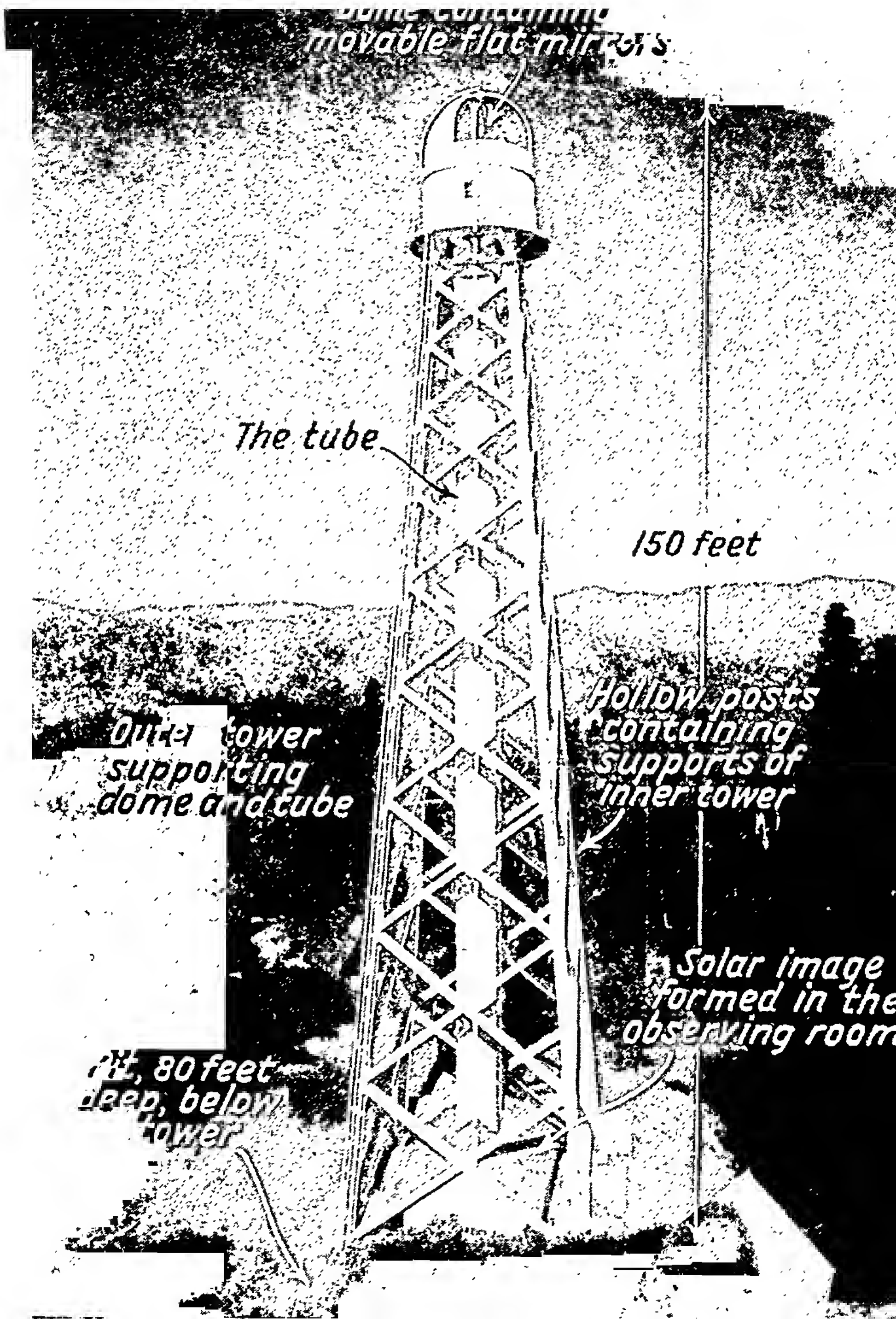


movable flat mirrors
The tube
150 feet
Hollow posts containing supports of inner tower
Solar image formed in the observing room

SECTION I

THE WONDERS OF THE HEAVENS

CHAPTER 1—THE SUN

To those of us who live in Britain our nearest city seems a very large place and London seems to be enormous. If we complete a cycle or motor tour of Great Britain we feel we have covered a tremendous area and that we should not care to do the same with the continent of Europe as the objective. Yet Europe is but one of five continents, and these combined occupy only a fraction of the area of the whole Earth.

Our imagination reels at the thought of the Earth's size and is really incapable of grasping the significance thereof. How then can we expect to be able to imagine the size and significance of some of the other planets that together with the Earth circle around the Sun and form the solar system? And how much more difficult a proposition is it for us to try to imagine the dimensions of the Sun, and to gain some idea of the composition of this great globe that maintains its heat and light throughout the ages and remains undimmed in its majestic brilliance.

The Earth's diameter is 7,920 miles, but that of the Sun is over a hundred times as great. In fact, if placed side by side, 109 planets of the same size as the Earth would be required to stretch from one side of the Sun right round to the other.

If a firm of contractors undertook to build up a body as large as the Sun, and if their transport arrangements enabled them to convey to the site every hour a quantity of material equal to the volume of the Earth, their contract would not be completed for 150 years, working three 8-hour shifts to the day. Mathematicians are able to tell us that the Sun's mass is 332,000 times that of the Earth and that its density is about one-fourth that of the Earth.

To express the Sun's mass in tons we should have to write down the figure 2 and follow it with 27 ciphers to show the number as 2,000 quadrillion! Few people can visualise a thousand, and even fewer can imagine a million, so that no one can hope really to comprehend what is represented by such an astronomical figure as 2,000 quadrillion.

It is known that, compared with the relatively solid Earth, the Sun is of a more gaseous nature. Remembering that every particle of matter attracts every other particle—as we shall explain in greater detail later—we are able to understand more clearly how it is that the Sun has such a powerful gravitational effect on the Earth and on the other planets that circle round it.

INTENSITY OF SUNLIGHT

The light given out by the Sun is the most intense light known—it is 150 times as bright as limelight and four times as bright as the electric arc.

The Sun's heat is enormous and several interesting calculations have been made in an attempt to illustrate it. For example, it has been determined that if the whole of the solar radiation could be concentrated on to a solid column of ice $2\frac{1}{4}$ miles in diameter stretching from Earth to Sun—about 93,000,000 miles—it would melt it in one second, and the resulting water would be turned to steam in not more than eight seconds!

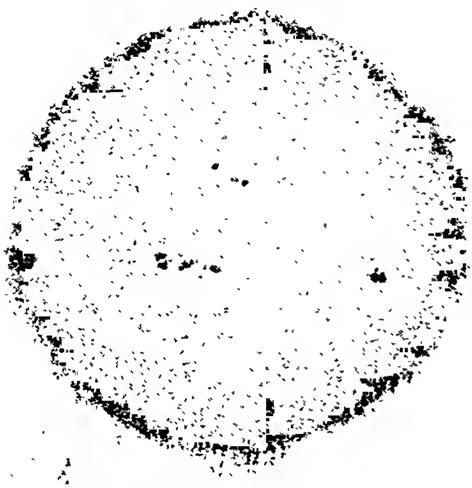


Fig. 1. The Sun, showing three groups of sunspots and characteristic fading at the limb.

An estimate of the surface temperature of the Sun places it at 12,000° F. and its radiation at over 1,000,000 calories per square metre per minute. To obtain this amount of heat by combustion would require the burning every hour of a layer of anthracite coal 16 ft. thick and extending over the entire surface of the Sun. Lord Kelvin calculated that if the Sun were composed of solid coal and produced its heat by combustion it would burn out in less than 6,000 years.

We must remember, too, that the Earth receives only a very minute quantity of the total heat and light that is radiated by the Sun. We can well illustrate this by supposing that the Sun's radiation is converted into money. If we take the Sun's annual expenditure as being £18,000,000,000, the Earth would receive an annuity of about £9 only. Yet if as little as 10 per cent. of this small quantity were cut off, large areas of the Earth would become frozen wastes. The remainder of the Sun's radiation passes into space and apparently is wasted, except where it falls on the other planets of the solar system.

Endless discussions have taken place as to how the Sun maintains its enormous output of light and heat, which does not seem to have appreciably diminished throughout the centuries. So far as the Earth's surface is concerned it would be difficult to attribute any changes in vegetable and animal life to a diminution in the amount of heat received from the Sun, for local conditions play a more important part in this respect. Otherwise, we might be led to suppose that the amount of heat received is increasing rather than diminishing, since we know that at times in the Earth's history the temperate zones were covered with a great sheet of ice many hundreds of feet thick. But although this has since melted away, it is not because of any increase in the heat of the Sun.

HELMHOLTZ'S THEORY

The German physicist Helmholtz (1821–94) advanced a theory that received considerable support. He suggested that the Sun's heat is the result of the energy of the Sun's gradual contraction. He found that a contraction of the Sun to the extent of 250 ft. per annum—slightly over a mile in 21 years—would be sufficient to account for the annual output of heat. On this assumption the deduction is that in 100,000 years the mean temperature of the Earth will be 5° lower than it is now. Other calculations suggest that even if contraction were taking place at the rate mentioned, the Sun's mass is so enormous that its temperature will remain more or less as it is for at least 10,000,000 years. As it is not possible to prove the theory by any measurements of the Sun's diameter, for some 10,000 years would have to elapse before any diminution would be measurable, we must leave the matter as it stands—an interesting speculation.

One other theory to be mentioned briefly is advanced by those who do not believe that the theory of contraction

accounts for more than a five-hundredth part of the energy of the Sun. The alternative theory, which involves rather abstruse speculation, is based on the supposition that the elements of the Sun are formed from hydrogen. If this is so, then the mass of their atoms should be exact multiples of the mass of the hydrogen atom. Actually, their masses are in general a little less than the calculated figure. It is possible, using an argument that was first brought forward by Einstein, to explain the energy of the Sun by assuming that the extra mass has been turned into radiant energy. Such a theory postulates a far older Sun and a much longer lease of life on its present scale than Helmholtz's theory of contraction.

THE SURFACE OF THE SUN

A photograph of the Sun (Fig. 1) shows it to be a globe with clean-cut edges that are less bright than the central part. Towards the extremity of the disc this darkening may amount to a loss of as much as 60 per cent. of the light at the centre. This shows that its surface is gaseous, for were the Sun solid or liquid its surface would appear to be equally bright at the edge and at the centre. The darkening of the edge, or "limb" as it is called, is caused by absorption of light by the gaseous envelope that surrounds the Sun, and which corresponds to the atmospheric envelope that surrounds the Earth.

The surface of the Sun presents a mottled appearance as though covered thickly with tiny elongated grains (Fig. 2). Over the surface are to be seen irregular streaks that are brighter than the surrounding surface. These are the *faculæ* (a Latin word meaning "little torches"). The *faculæ* are most numerous in areas away from the poles, where, in fact, they are not often seen. They are best seen towards the limb where, because the relative brightness of the surrounding surface is somewhat dimmed, as already explained, they are more conspicuous. Actually, the *faculæ* are the crests of great clouds of vapour arising from the depths of the Sun, and they may measure 40,000 miles in length and 5,000 miles in breadth, or even more.

Very often spots are seen on the surface of the Sun, as shown in Fig. 1. These spots vary in size from the tiniest point to huge dark markings that look like blots of ink on a clean plate. The Sun always used to be regarded as a symbol of unblemished purity, and when Galileo discovered spots on it through his newly invented telescope, over 300 years ago, he was very perturbed at what he saw. The explanation of them is as follows. The surface of the Sun that we see—called the "photosphere"—is a layer of highly heated gases that surrounds the central mass, and sunspots are openings in this gaseous envelope.

Sunspots are like safety valves—they allow highly compressed and heated gases to escape from the Sun's interior through the agitated photosphere. Sunspots are whirlpools, or vortices, in the

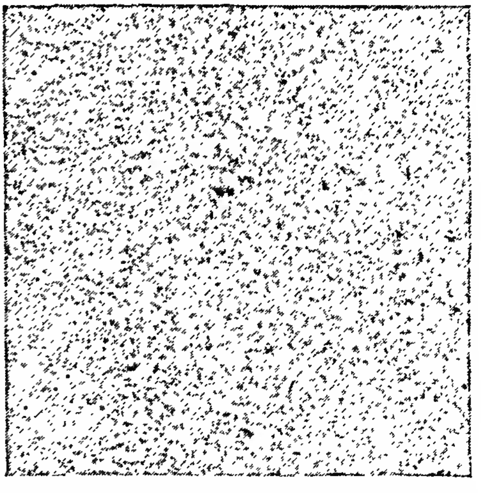
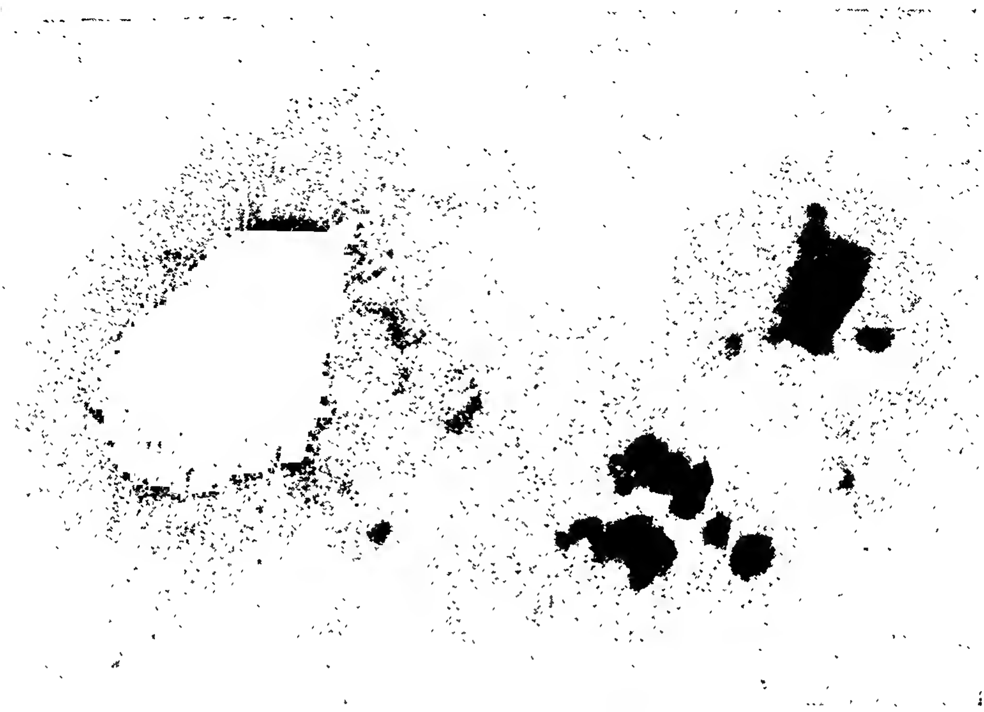


Fig. 2. The Sun's surface, showing blurring due to rise of heated gases from the central mass.



3. Large sunspot group photographed at Greenwich Observatory. The dusky penumbra together with several smaller spots can be clearly seen in this picture.

lar atmosphere. When a gas under essure is suddenly released and allowed expand, it cools in accordance with a tural law, and this is what happens hen a sunspot is formed. What is low the photosphere we can only rmise. When the great solar storms at cause sunspots take place, the otosphere is torn apart and we can see through the "rift in the clouds" that the depths below appear black (Figs. 3 and 4). From this we might suppose that the interior of the Sun is cool, but we must remember that although a sunspot appears black it is only so in comparison with the excessive brilliance of the photosphere, just as an arc light appears black if held against the disc of the Sun for comparison.

Although sunspots often assume fantastic shapes, as a rule they are more or less circular in outline—at any rate they are nearly always so when they first appear. They are of all sizes—some measure up to 100,000 miles in diameter —and most of them could swallow up the Earth with ease (Fig. 12). One of the largest ever seen—in 1905—was so large that 40 Earths laid side by side could have passed through it without touching its edges. Such spots as these can be seen easily with the naked eye when the Sun is obscured slightly by mist or cloud, or by looking through smoked glass, or through the dark part of a photographic film.

THE SUNSPOT CYCLE

Although there are nearly always some spots on the Sun, there are more in some years than in others. They come in waves, fluctuating every eleven years and forming a cycle. This sunspot cycle was first discovered in 1852 by Schwabe, a German chemist, who made all his observations with a small hand telescope. He was awarded the Gold Medal of the Royal Astronomical Society for "the

indomitable zeal and untiring energy displayed in bringing his research to a successful issue". The years 1917, 1928, and 1939 were those of sunspot maximum, and the cycle is illustrated by the lower curve in the graph shown in Fig. 5.

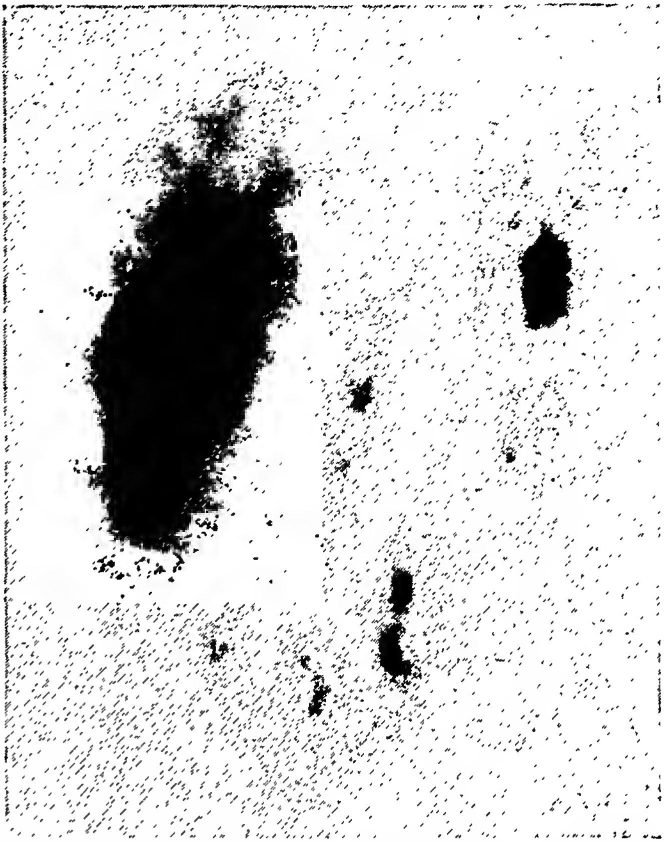


Fig. 4. The same spot as in Fig. 3, three days later. It has been split by a bridge and some of the smaller spots have disappeared.

Although they look so small, and although they are situated so enormously far away, the Earth is affected by sunspots in more ways than one. It has been proved that the vortices forming the spots are electrical, and in 1922 it was discovered by G. E. Hale, the Director of the Lick Observatory, that the spots are associated in pairs of opposite magnetic polarity (Fig. 6). They particularlyaffectmagnetic instruments and deflect galvanometers, the increase and decrease of their magnetic activity synchronising with the eleven year sunspot cycle, as may be seen from the upper curve in Fig. 5. On more than one occasion telegraphic communication has been completely held up by magnetic storms originating in the Sun.

'These magnetic storms are generally accompanied by extraordinarily beautiful displays of the aurora in both northern and southern hemispheres (Fig. 7.) The wonderful auroral streamers and curtains of coloured light are caused by the arrival of atoms or electrified particles shot out from sunspots, and by other forms of accompanying solar activity. Their interference with wireless reception (Fig. 8) is probably brought about by the formation of layers, like the Heaviside

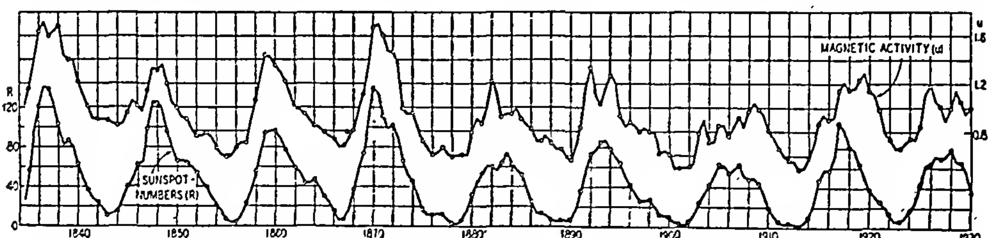


Fig. 5. Relation of sunspot numbers (lower graph) to magnetic activity (upper) from 1835–1930.

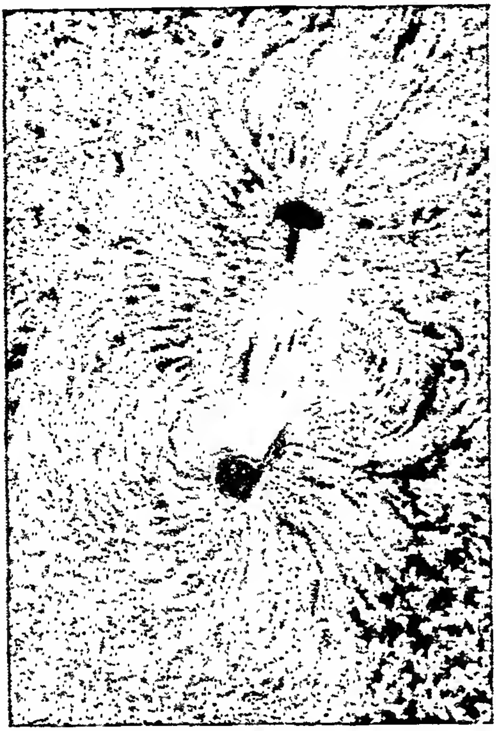


Fig. 6. Cloud of hydrogen bridging two sunspots. Notice the counter—clockwise movement.

layer, that reflect the radio waves back to Earth. Such layers probably exist at distances up to 3,000,000 miles from the Earth's surface. At this distance there can be no trace of air in which the particles could remain suspended as they do in the lower reflecting layers. Thus it seems probable that the reflection is due to electrified particles actually travelling from the Sun to the Earth, and it is probable that it is these particles that cause the aurora (Fig. 9).

When a tree is cut down, a section of the trunk shows a number of rings that run concentrically from the centre (Fig. 10). As each of these rings represents a year's growth we can tell the age of the tree by counting the number of the rings. Almost any tree will show that the rings are not of equal thickness, which is quite understandable since during dry summers less wood will have been grown than when the tree had plenty of moisture. Thus the tree forms a natural record of the weather ex-

Fig. 7. The Aurora Borealis is a cathodic ray discharge, associated with solar activity. It occurs about seventy miles above the Earth and is most frequently seen in the Arctic regions.

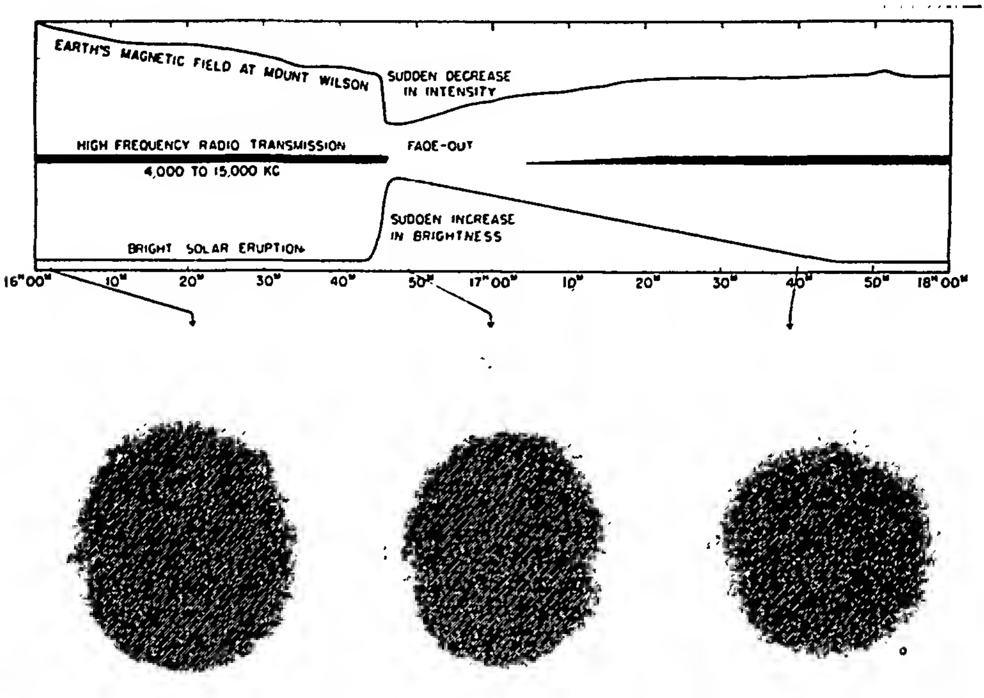


Fig. 8. The relationship between the activity of sunspots and the Earth's magnetic field. As the solar eruption (photographed in the lower half) developed, there was a sudden decrease in magnetic intensity and a fade-out of radio signals, as shown by the graph above.

perienced during its life-time. By studying these rings it has been found that their thickness varies over a period of 11 years, the same period as constitutes the sunspot cycle.

When the sunspots are most numerous, the summers are moist and wet, and so the tree grows more wood and the rings are thicker. Professor A. E. Douglass, an American astronomer, has gone further than this—he has even been able to determine what the weather was like at about the time of the Norman Conquest! He has studied sections of trees used by Indians in the construction of their ancient dwellings. One such tree (Fig. 11), cut down in A.D. 1260, shows by its rings the variations of climate from that year back to A.D. 1073—truly a remarkable record, the existence and interpretation of which has only been realised quite recently.

If we watch a sunspot day by day we notice that each day it moves a little nearer to the edge of the Sun, due to the fact that the Sun rotates on its axis, exactly as do the Earth and the other planets. Figs. 3 and 4 show how a large spot moves in a few days. The spot shown in Fig. 4 is the same spot as shown in Fig. 3 but in this case the photograph was taken three days later. Whereas in Fig. 3 we see the spots "full in the face," as it were, in Fig. 4 the spots appear to be more edge-ways because in the intervening period they have moved nearer to the limb of the Sun. The photograph shows, too, the changes that have taken place during the three days, for a bright bridge has developed across the dark spot and many of the smaller spots have disappeared, covered over by the photosphere. Despite this, the small groups

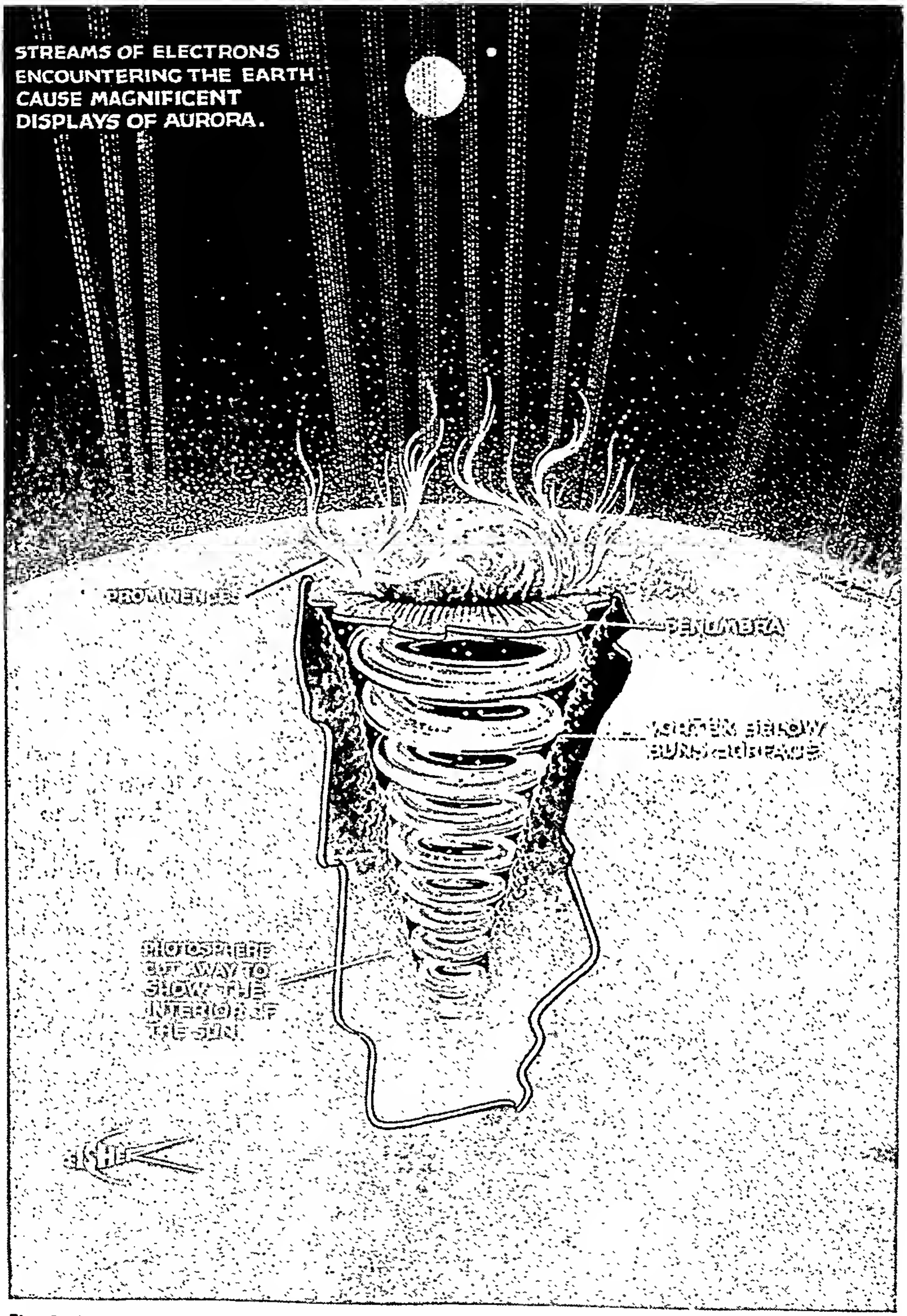


Fig. 9. Structure of a sunspot. Sunspots are huge vortices in the envelope of incandescent material round the Sun—safety valves allowing gases to escape from inside.

retain their characteristic appearance and are recognisable as being the same groups as shown in Fig. 3. The movements of sunspots are more clearly shown in the sequence of separate photographs in Fig. 12, where the same group of spots is depicted over a period of five days. The spots are all shown as having moved from right to left.

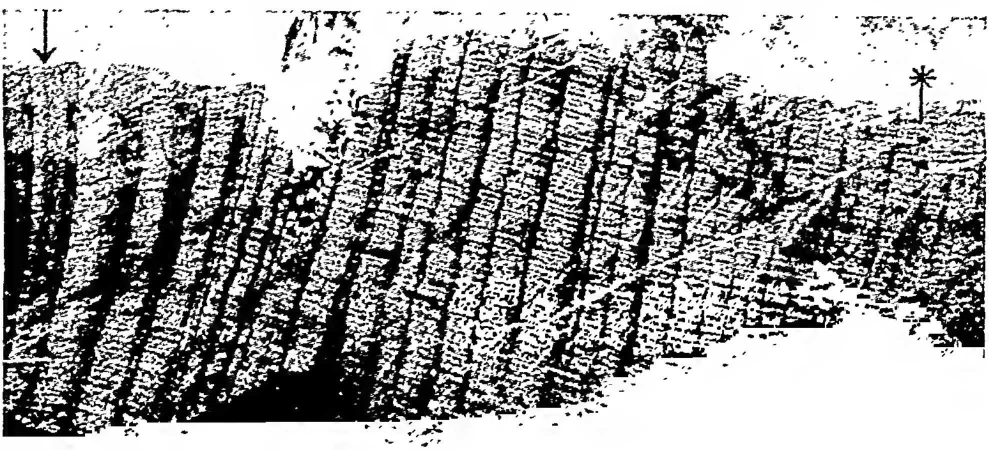
THE "SYNODIC PERIOD"

The Sun rotates on its axis in a period of about $25\frac{1}{3}$ days, but as the Earth in the meantime has moved some distance around the Sun, the time of rotation (known as the "Synodic period") appears to us to be about $27\frac{1}{3}$ days. This rotation period applies only to the regions near the Sun's equator, for the regions between the equator and the poles rotate more slowly, some taking two and a half days longer, and those near the poles themselves considerably longer.

Owing to this rotation of the Sun, a sunspot that appears on one limb of the Sun is slowly carried across the face in fourteen days, to disappear round the other limb and remain lost to sight for a further fourteen days. It is not always certain, of course, that the same spot will reappear at the expiration of this period, for it may well have been covered up by the photosphere while it is moving across the averted face of the Sun.

Fig. 10. Section of an oak log, showing the concentric annular rings. Each of these rings represents one year's growth.

As it revolves in its orbit around the Earth, the Moon occasionally comes between the Earth and the Sun, shutting off the sunlight and causing an eclipse to take place. Although the Moon



Courtesy A. E. Douglass.

Fig. 11. A log taken from a ruined Indian dwelling. From this scientists have discovered America's mediaeval weather conditions. The arrow indicates the growth of the tree in 1247, the star, in 1275 ; the size of these rings indicates the rainfall for the year.

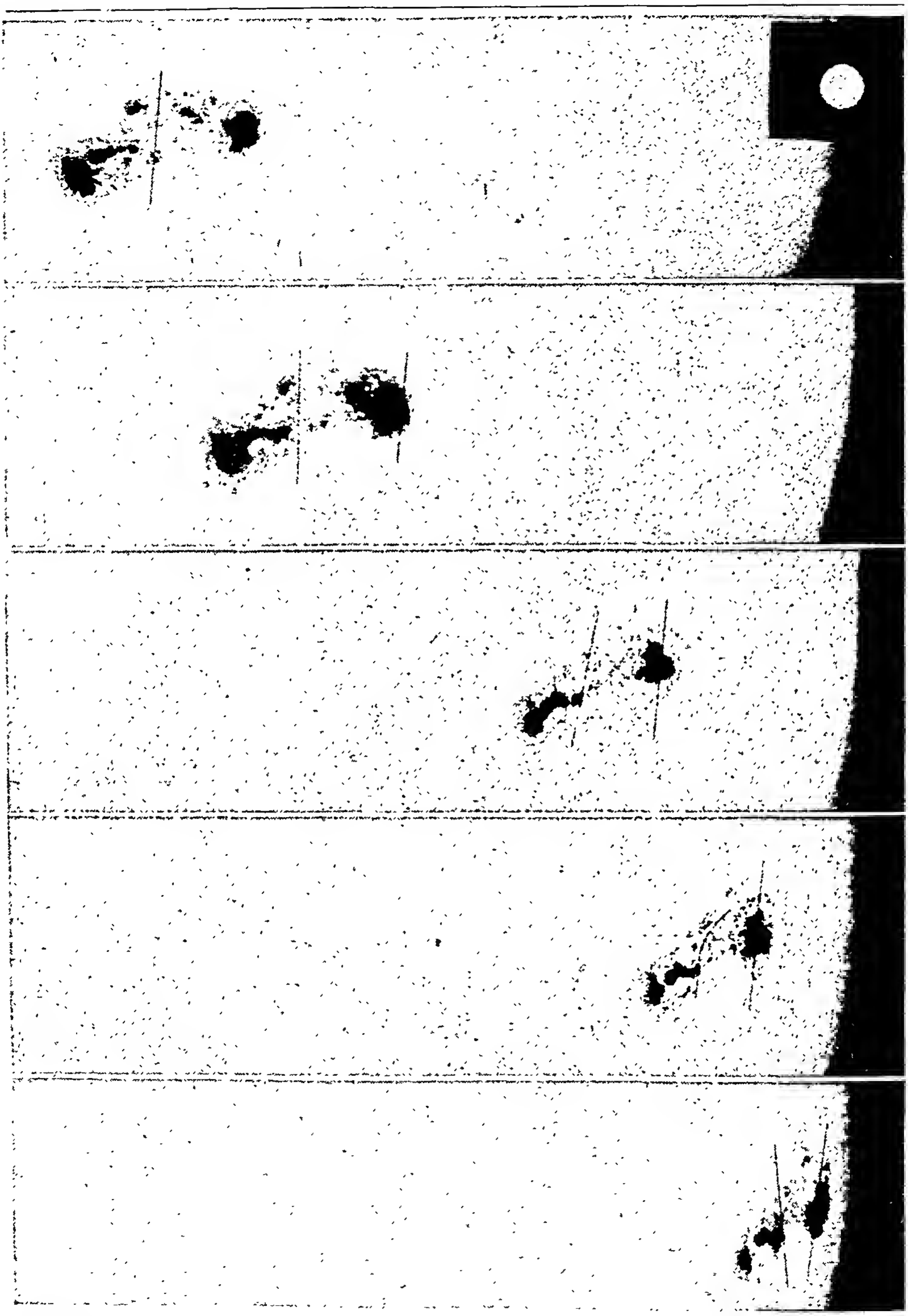


Fig. 12. The day by day movements of a sunspot group observed at Mount Wilson showing how the spots are carried slowly across the face of the Sun towards the limb by its rotation. Inset shows the size of the Earth in comparison with these huge sunspots.

travels completely around the Earth every month, it is not always that the three bodies are directly in line—sometimes the Moon is too high and sometimes too low, as it were, and no eclipse takes place (Fig. 13). If the Moon does not completely cover the Sun, only part of the light is cut off. This is a partial eclipse, and its extent varies according to the relative positions of the Moon and the Earth and to the position of the observer on the Earth. In Fig. 14 the picture on the left shows the partial eclipse of 28th March, 1922, in which only a small part of the solar disc was obscured by the Moon. The centre figure (Fig. 14) shows the partial eclipse of 8th April, 1921, an eclipse of greater magnitude; both illustrations depict the maximum phase of the eclipse.

Again, if the Moon is at such a distance from the Earth at the time of the eclipse that its apparent diameter is less than that of the Sun, then an annular (Latin *annulus*, "ring") eclipse occurs. Such an eclipse, that of 1st November, 1929, is illustrated by the figure on the right (Fig. 14). From Great Britain this particular eclipse was seen as a partial eclipse, one fifth of the Sun being covered by the Moon. From Sierra Leone, however, the whole of the Sun was covered except for a ring of light that surrounded the Moon, causing an annular eclipse.

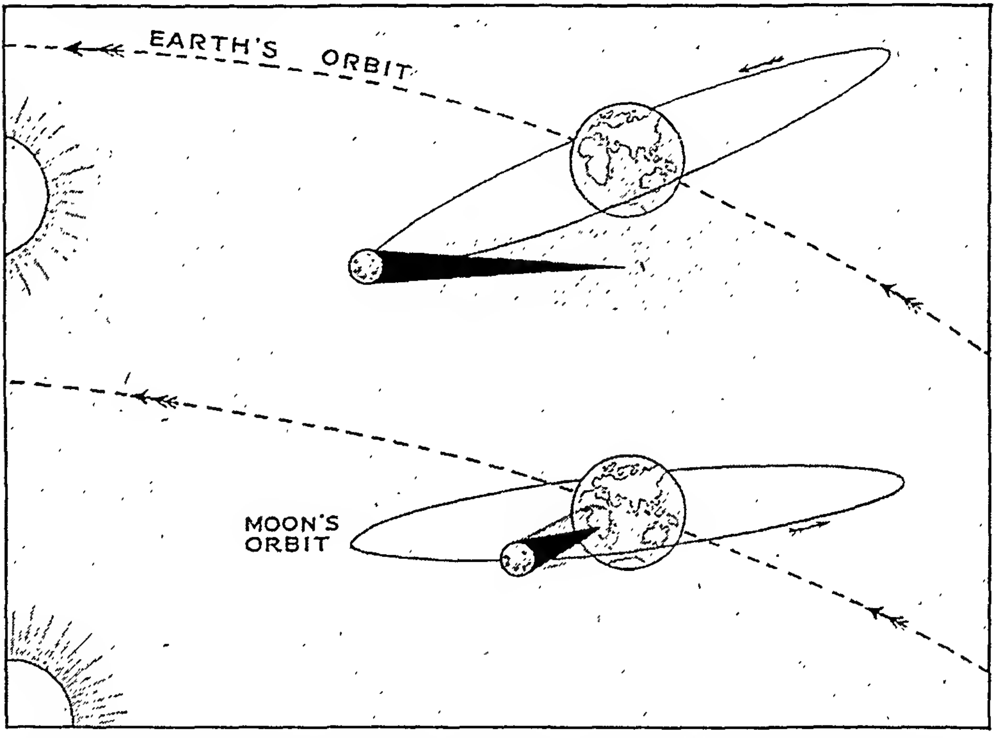
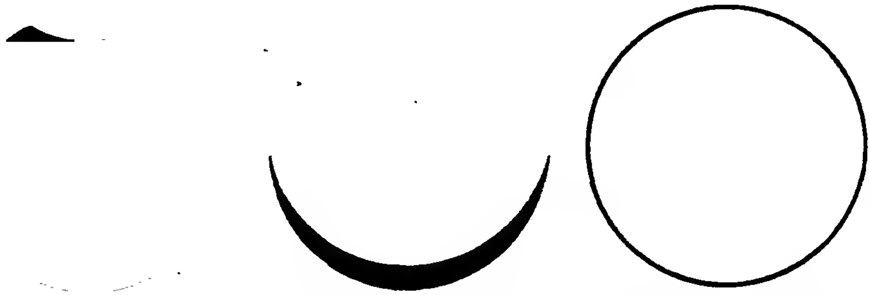


Fig. 13. The relative position of the Earth, Sun and Moon determine when a solar eclipse occurs. Only rarely are the three bodies in a direct line as shown in the lower half of the picture. It is only when this rare coincidence occurs that an eclipse can take place.

Fig. 15 makes clear the reason for these varying phenomena. The top illustration shows the shadow of the Moon falling on the Earth so that a total eclipse is caused to take place in Africa; *b* shows a partial eclipse, as seen from Africa; *c* shows the Moon too distant



28TH MARCH 1922 8TH APRIL 1921 1ST NOVEMBER 1929

Fig. 14. On the left is a small partial eclipse of the Sun and in the centre, a large partial eclipse On the right, is an annular, or ring, eclipse ; here the Moon does not cover the Sun completely

from the Earth to cast a complete shadow on the Earth with the result that an annular eclipse occurs.

PARTIAL AND TOTAL ECLIPSES

Although they have some degree of interest, neither partial nor annular eclipses are as interesting or as important as total eclipses. None of the characteristic phenomena of the total eclipse are seen, because in neither partial nor annular eclipses is the whole of the sunlight cut off. The next partial eclipse of the Sun, visible from Britain, will occur on 10th September, 1942, when a third of the Sun will be covered by the Moon. After that there will not be another until 9th July, 1945, when three-fifths of the Sun will be obscured; this eclipse will be seen as a total eclipse in Norway.

During a total eclipse the shadow of the Moon falls on the Earth and moves over land and sea. Only along the line thus traversed by the shadow does a total eclipse take place (Fig. 16). On either side of this "line of totality" are broad belts that may extend up to 2,000 miles, and from places within these areas only a partial eclipse will be seen. Actually the line of totality is never more than 170 miles in width, the duration of a total eclipse never being longer than eight minutes under the most favourable conditions.

Arising out of these factors we see that an eclipse of the Sun is to a certain extent a local phenomenon—an eclipse that may be total in Spain may only be partial in France, and to an even less degree in England, the location of the line of totality being the determining factor.

Eclipses have been recorded carefully from the earliest times, and so well known are the movements of the heavenly bodies that the calculation of eclipses is a very precise matter. The earliest mention of a solar eclipse—for which the date has been worked out with a high degree of probable accuracy—is recorded in an ancient Chinese manuscript. Here it is picturesquely stated that " on the first day of the last month of autumn, the Sun and Moon did not meet harmoniously in Fang." Fang was part of the heavens now marked by four stars of the constellation of Scorpio Investigations show that this inharmonious meeting of the Sun and Moon without doubt refers to the solar eclipse that occurred on 22nd October, 2136 B.C

We can date with unimpeachable accuracy eclipses of the past, and many eclipses in history have been identified and definitely dated. We know, for instance, that an eclipse occurred at Ur at 11 a.m. on 8th March, 2283 B.C., and that the eclipse at Ithaca, mentioned in Homer's *Odyssey*, occurred at 11.41 a.m. on 10th April, 1178 B.C. From the calculation (made in 1925) of this eclipse it was attempted to calculate the date of the fall of the city of Troy, which most probably occurred in the year 1200 B.C.

Fig. 16 shows the line of totality —across North Wales, Cheshire, Lancashire, Yorkshire, and Durham— of the total eclipse of 29th June, 1927. This was the first total eclipse to be visible from this country since 1724; the central line ran from Criccieth, in North Wales, to Hartlepool in Durham. Totality extended for about 15 miles on each side of this central line for a duration of about 23 seconds.

BRITAIN'S NEXT ECLIPSE

There will not be another total eclipse visible from Britain until August 1999, when the line of totality will pass over Cornwall. The next total eclipse of the Sun will take place on 1st October, 1940 and will be visible from Brazil and South Africa but invisible to observers in Great Britain.

During the brief period of an eclipse when all direct sunlight is cut off from the Earth, the brighter stars and planets

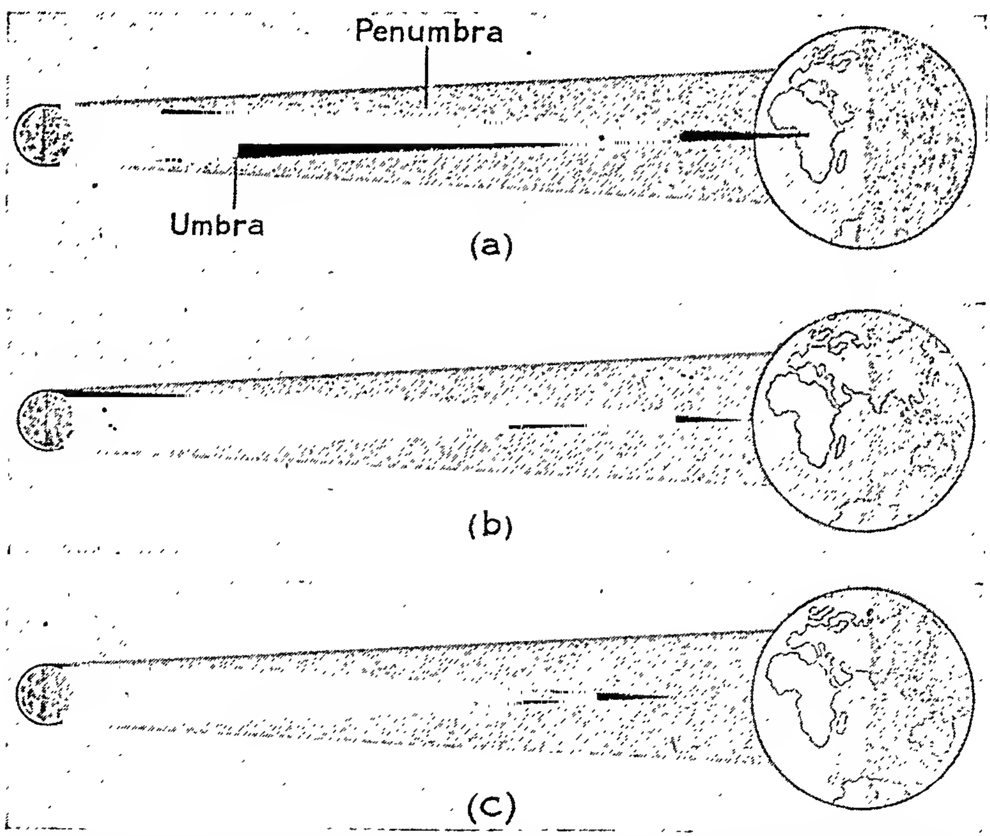


Fig. 15. The three kinds of solar eclipses and how they are caused ; (a) total eclipse ; (b) partial eclipse ; (c) annular, or ring, eclipse. The figures are not, of course, drawn to scale.

are visible in the sky even though it may be midday. "There was such an eclipse of the Sun," wrote Diodorus Siculus who lived in the last century before Christ, describing the eclipse of 15th August 310 B.C., which, of course he did not himself observe, "that the day wholly put on the appearance of night, and the stars were seen in all parts of the sky".

At the instant of totality, too, there are seen pearly streams of light surrounding the interposed body of the Moon (Fig. 17). This is the corona (Latin: "crown") that, although always present around the Sun, is invisible at other times because of the overpowering brilliance of direct sunlight. The corona varies in appearance and extent at

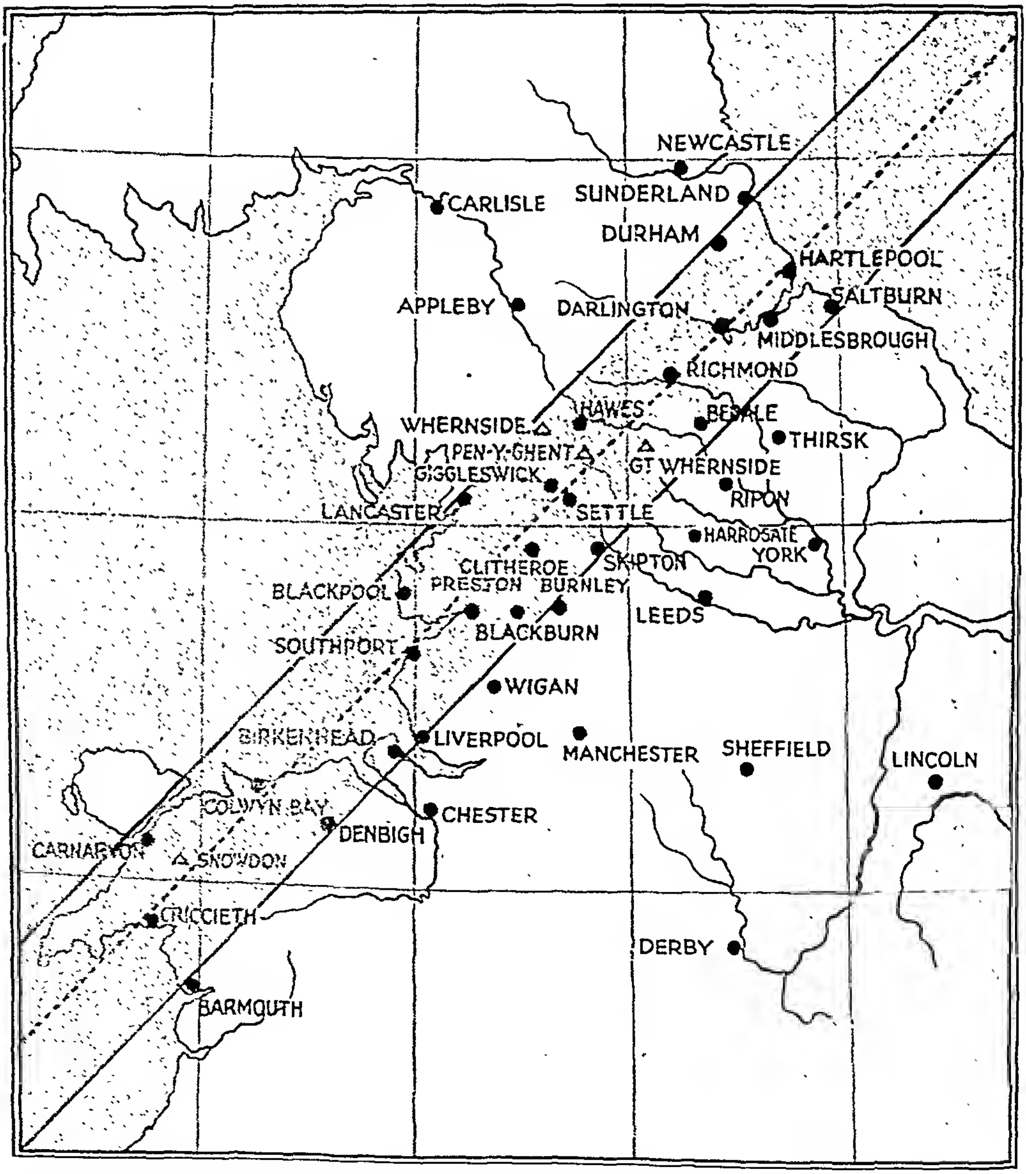


Fig. 16. Line of totality during the eclipse of the Sun on 29th June, 1927. In the 30 mile wide shaded band the eclipse was total, whilst outside this line the eclipse was seen as a partial one.

Fig. 17. The corona and solar plumes, seen only at the time of total eclipse.

different eclipses, the rays being affected both in shape and length by the same periodic ebb and flow of solar activity that causes the sunspot cycle.

The corona does not form part of the Sun's surface, nor does it share in its rotation. Of eruptive and electrical origin, it is probably due to streams of atoms and electrified particles that are shot out from the Sun with tremendous velocity. The arrangement of these particles must be of inconceivable tenuity, and the particles themselves must be in a perpetual state of movement under the opposing forces of attraction and repulsion. The arrangement is probably due to some electro-magnetic action, a similar streaming effect having been reproduced in the laboratory by means of electrical discharges in partial vacua (spaces almost devoid of matter).

During an eclipse there are also to be seen, around the dark edge of the Moon, vivid flame-like projections known as prominences that shoot out from the chromosphere, or solar atmosphere (Figs. 18-21). Although at one time these could only be seen during an eclipse, the application of an instrument known as the spectroscope made it possible to see them at other times. We shall deal later with the spectroscope and it will be sufficient here to remark that this invaluable instrument was introduced in 1860 by Kirchhoff.

Subsequently (in 1891) it was found possible to study the prominences photographically by using only certain light rays—such as those given out by calcium—and eliminating the other unwanted rays. Observations of this kind

Fig. 18. A solar prominence and the corona during an eclipse.

are made possible by the spectroheliograph, invented by G. E. Hale, the Director of the Lick Observatory at Mount Hamilton, California. The spectroheliograph will be described later, in our chapter dealing with Light.

Fig. 19. A prominence during an eclipse. The uneven edge of the Moon, due to the lunar mountains, is clearly seen.

The prominences just mentioned consist of enormous masses of gas—particularly of hydrogen and calcium—ejected from sunspots under great pressure. Prominences of the flame type "flicker" like the flames of our firesides, and in some cases rise to extraordinary heights above the Sun's surface, ejected at speeds of hundreds of thousands of miles an hour (Figs. 19, 20 and 21). Some prominences are cloud-like in appearance and seem rather more permanent than those of the flame type, sometimes lasting for several days. They are generally connected with the Sun's surface by thin columns of gas, which bear some resemblance to the "funnel" of a waterspout.

From our brief account of the Sun it is evident that it provides science with one of its greatest mysteries and marvels. Man has learned a great deal about it, but there is yet much to be learned, and much that will probably never be known. For instance, it is calculated that the temperature at the Sun's centre must be in the neighbourhood of 50,000,000° —whether F. or C. seems immaterial—and its pressure must be equal to as many atmospheres. We cannot conceive how matter will behave under such conditions—even atoms must be broken down, constituting a state of things of which we neither have nor probably ever will have experience.

In the attempt to solve the mysteries of science, particular importance is attached in every branch to determining the bases from which subsequent calculations or deductions are made. Where these fundamental constants, as they are called, cannot be determined with sufficient accuracy at the outset, the endeavour is continually to revise the adopted standards with a view to increasing accuracy in the light of more recent knowledge.

Fig. 20. A huge cloud of hydrogen gas being ejected from the Sun at a velocity of hundreds of miles a second. A comparison with Fig. 21 will show the immense speed at which the cloud travels.

In Astronomy it is always desirable to obtain a greater refinement in regard to the measurements of the heavenly bodies—particularly of the masses of

Fig. 21. The hydrogen cloud shown in Fig. 20, having risen to a height of 350,000 miles in less than an hour.

the planets and of the Moon — and of the various motions of the Earth's axis. Perhaps the most important of all is the determination of the Earth's distance from the Sun, for on an accurate determination of this factor depend many other measurements. For example, unless the Sun's distance be determined accurately we cannot know the exact radius of the orbit of the Earth. Any error in this repeats itself in many ways—such as in calculating the radii of the orbits of all the other planets. As a rule such calculations involve computations by cube, so that even a small error becomes enormously multiplied in the final result. This may be seen, for example, from the fact that an error in observation that places the Moon nearer to or further from the Earth by 100 miles will affect the calculation of the Sun's distance by no less an amount than the figure of 16,000,000 miles.

Work on the problem of the Sun's distance must be done with a degree of accuracy that would enable scientists to measure exactly the angle subtended by

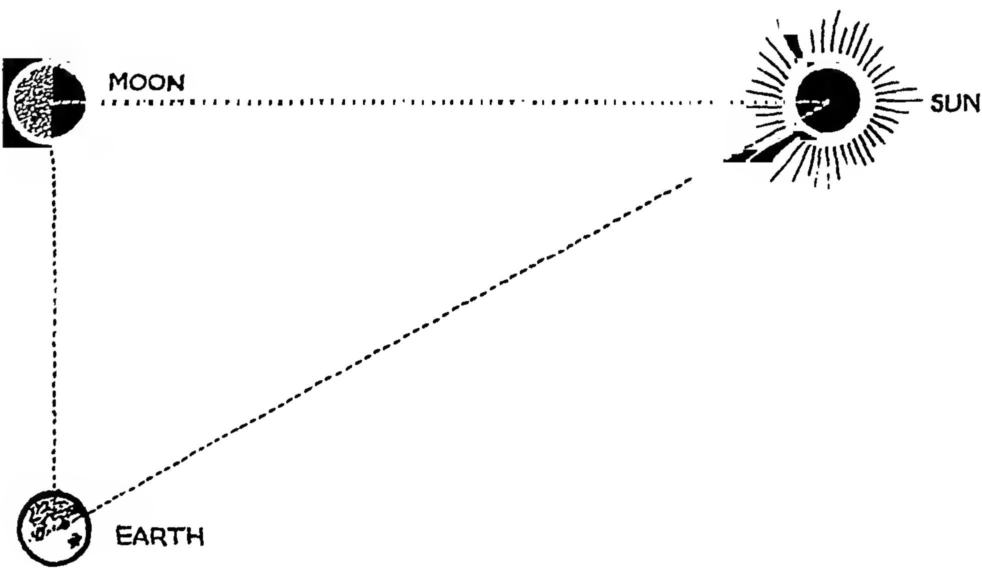


Fig. 22. How Aristarchus tried to measure the distance of the Sun. When the Moon is exactly half illuminated, the angle between Earth, Moon and Sun is a right angle.

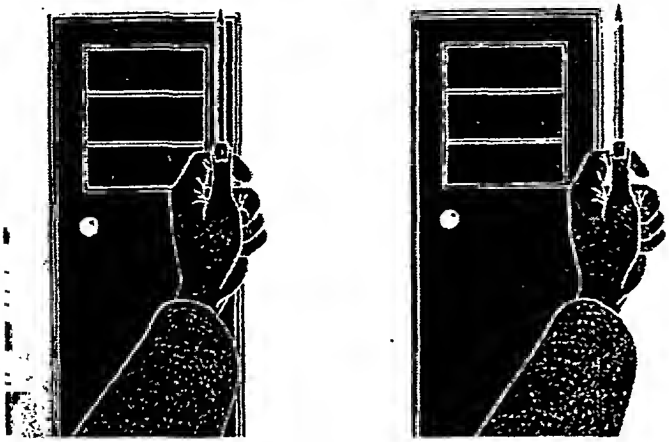


Fig. 23. Effect of parallax. (Left) what you see with left eye closed and (right) with right eye closed.

a halfpenny held at a distance of 2,000 ft. from the eye of the observer. The angle thus to be measured, which is called the "solar parallax", is that which the Earth's equatorial radius subtends at the distance of the Sun.

THE MEANING OF PARALLAX

The astronomers of old made ingenious attempts to solve the problem, of exactly how far distant the Sun is, and although their efforts were absurdly inaccurate, some of the methods they employed were scientifically sound. The earliest effort was made in the third century B.C. by Aristarchus of Samos, who endeavoured to find how many times greater was the Sun's distance from the Earth than was the distance of the Moon. Fig. 22 shows how he attempted to do this. When the Moon is exactly half illuminated—that is to say, when it is in the first or last quarter—the angle at the Moon between the observer on the Earth and the Sun is a right angle. If the Sun were only at the same relative distance from the Earth as shown in the diagram, the angle Sun, Earth, Moon would be 75°. It follows naturally, of course, the nearer the Sun comes to the Earth, the smaller will this angle be.

Geometrically sound, the method is quite impracticable, for it is impossible to determine the instant when the Moon is exactly half illuminated, and a very slight error here falsifies the result. Aristarchus found that the angle formed by the Sun and Moon with the Earth was 87° when the Moon was half illuminated, and calculated therefore that the Sun was eighteen to twenty times as far away from the Earth as the Moon. By this measurement, Aristarchus placed the Sun at a distance of about 4,500,000 miles, or about twenty times less than the actual distance.

Of the several methods of measuring the Sun's distance one of the most important is that based on a principle employed in 1673 by G. D. Cassini. This noted Italian astronomer attempted to solve the problem by first measuring the distance of Mars. This depends on measuring the change in the apparent position of a distant object as seen from two different positions. For example, look with the right eye only at an object close at hand and note its position with regard to the distant background. Now cover the right eye and without moving your position look at the same object with the left eye. The object seems to have moved to the right, by an amount that depends on the distance of the object from the eye (Fig. 23). The apparent shift in position is due to the fact that our eyes are about 3 in. apart and therefore the point from which we see the object with the right eye is not quite the same as that from which we view it with the left eye. The distance that the object appears to move

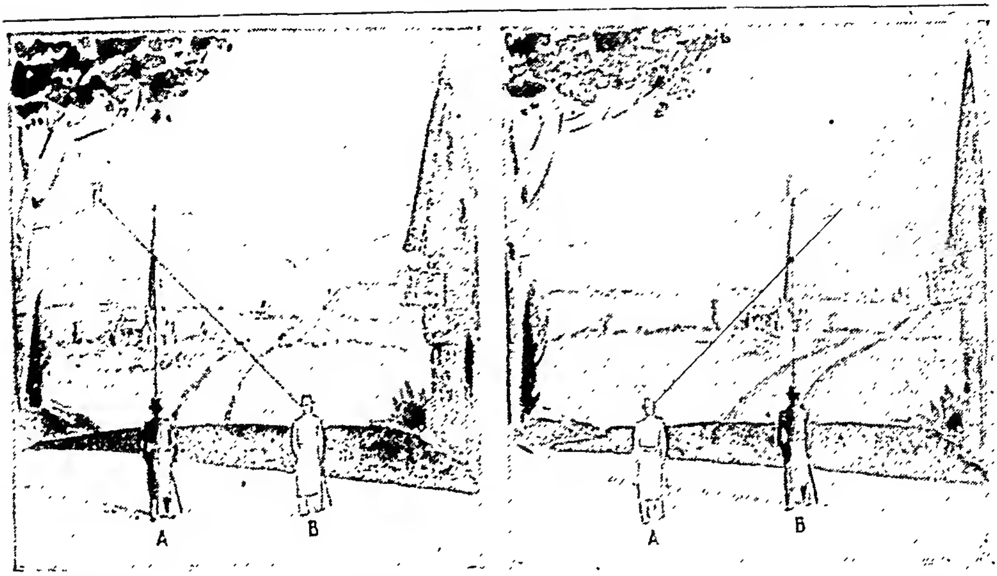


Fig. 24. How the position of an object in relationship to a third fixed point appears to alter when it is viewed from two different positions. The apparent movement is called parallax.

is as the width between our eyes would appear to anyone who looked at us from the position occupied by the object in question. This apparent movement of an object is called "parallax", a Greek word meaning "shift". Obviously, if we can determine the parallax of a heavenly body we shall be able to ascertain its distance, our calculations being based on the fact that the greater the distance of the object the smaller will be the parallax.

FINDING THE PARALLAX

There is a limit to the parallax that can be seen by alternatively viewing with each eye and it becomes necessary to increase this "base line" for more distant objects.

This can be done quite easily by noticing the position of the distant object in regard to some object behind it and at a greater distance, and then walking a few feet to the right or left, from which position a parallax may be obtained (Fig. 24). Another way is to station a second observer at the other point and for each observer to measure the angle subtended by the distant object.

This is precisely what was done in measuring the distance of Mars. By arrangement, Cassini at Paris, and Richer at Cayenne in French Guiana, simultaneously measured the angle subtended by Mars against a background of distant stars, the two observers being separated by the enormous base line of 4,500 miles. This resulted in the position of Mars, in regard to the stars near it, appearing slightly different to each observer (Fig. 25). From the measurements thus obtained they were able to obtain the two angles at the base of a triangle joining Paris and Cayenne to each other, and each of them to the

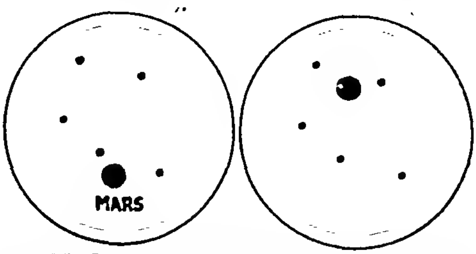


Fig. 25. Position of Mars in relation to other stars as seen from Paris (left) and Cayenne (right).

planet (Fig. 26). The resulting triangle was easily measured and the distance of Mars was determined. Then by applying one of Kepler's laws of motion, it was possible to calculate the distance of the Sun from the Earth. Cassini's figure gave a parallax of 9·5 seconds, placing the Sun's distance at 87,000,000 miles, a result that was only some 5,900,000 miles less than the mean distance. Though 5,900,000 seems an immense amount, this was comparatively, not a bad approximation.

DISCOVERY OF EROS

The problem of measuring the Sun's distance was considerably simplified when, in 1898, the minor planet Eros was discovered. We shall describe the minor planets later, and in the meantime it will be sufficient for us to say that Eros is a very small body, probably not more than 20 miles in diameter. As seen in the telescope there was nothing to lead its discoverer (Witt of Berlin) to suppose that he had found an object that differed in any way from the hundreds of other known minor planets, but later it was found that the discovery was of the highest importance. The particular fact of interest about this planet is that it moves in an orbit that is highly eccentric —so much so that on certain occasions the planet comes to within less than 14,000,000 miles of the Earth. As Mars can never be nearer to us than about 35,000,000 miles in the most favourable circumstances, little Eros has the distinction of being, with the exception of the Moon, our closest celestial neighbour whose orbit is accurately known.

Such a near approach as that of Eros gives us a much better opportunity to determine its parallax than in the case of Mars. In 1900 it was arranged to observe the position of Eros from many widely separated observatories, and to reduce the resulting observations to a common form. The work occupied ten years and gave as a result a solar parallax of 8·80 seconds, indicating a mean, or average, distance of the Earth from the Sun of approximately 92,900,000 miles.

Let us see if we can get some idea of what this distance of 93,000,000 miles means. A million is one thousand thousand—1,000,000. What this implies may be realised better by the fact that a watch that ticks once a second would require 1 week, 4 days, 14 hours (278 hours), to tick a million times. Incidentally, a billion is one million million (1,000,000,000,000), to tick off which the watch would require 31,735 years.

DISTANCE OF THE SUN

We know that the "Coronation Scot" does the journey from London to Glasgow (401 miles) in about six and a half hours. If we could lay a railway

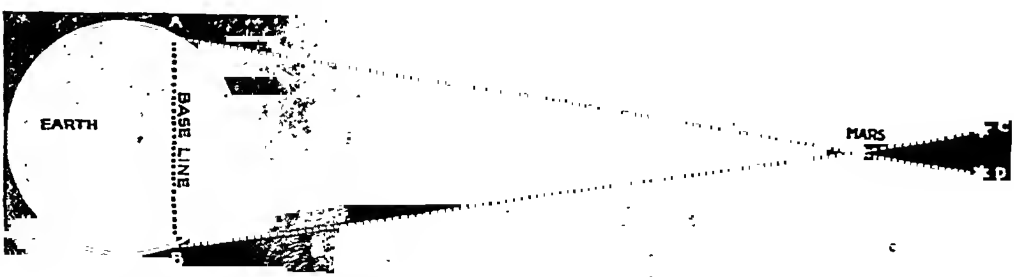


Fig. 26. How the Earth is used to determine the distance of a planet. From A, the position of Mars appears to be at D, from B at C. Taking a triangle from the base line on the Earth, A B the exact distance of the planet can be calculated without difficulty.

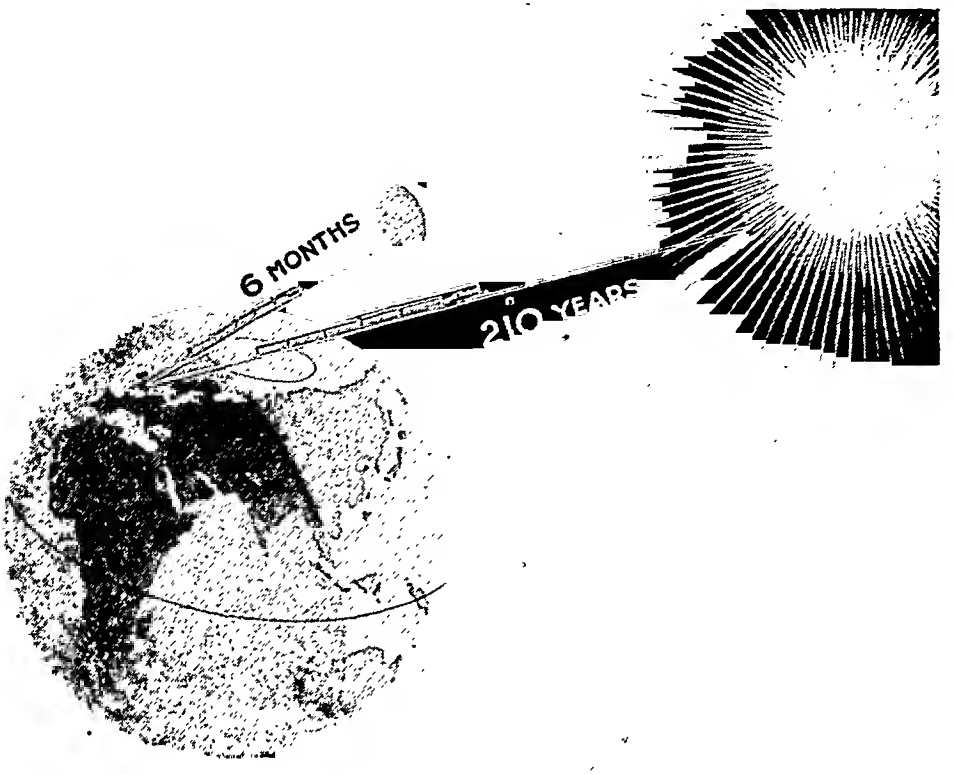


Fig. 27. How enormous are the distances separating the Earth from the Sun and Moon, can be judged from the fact that the Coronation Scot, travelling day and night, would take six months to reach the Moon and 210 years to reach the Sun, without any stops for refuelling.

to the Moon and arrange for the train to run day and night, without stopping for coal or water, it would reach the Moon in six months (Fig. 27). For the same train to reach the Sun would require over 200 years—so that had King George II taken a ticket he would not yet have arrived at his destination!

Yet another illustration may be given to bring home some idea of the enormous distance we are considering. Although when we burn our finger with a cigarette we seem to feel pain at the same instant, actually this is not the case, for an appreciable fraction of time elapses before the record of the sensation reaches the brain. A shock of this kind is communicated by our nerve impulses at a speed of about 100 ft. a second, or 1,637 miles per day. If we could imagine a young child with an arm so long that he could reach up and touch the Sun with his fingers, he would have time to grow to a ripe old age and die, before the sensation of pain could be communicated from his fingers to his brain. That is to say, he would not live long enough to feel the pain of this gigantic burn. If we consider this fact carefully we should be able to form some faint conception of astronomical distances.

We now leave the hot Sun, the source whence the Earth derives its light and heat, and upon which all its forms of life depend, to turn, in the next chapter, to a consideration of the lifeless Moon, the Earth's nearest neighbour in space.

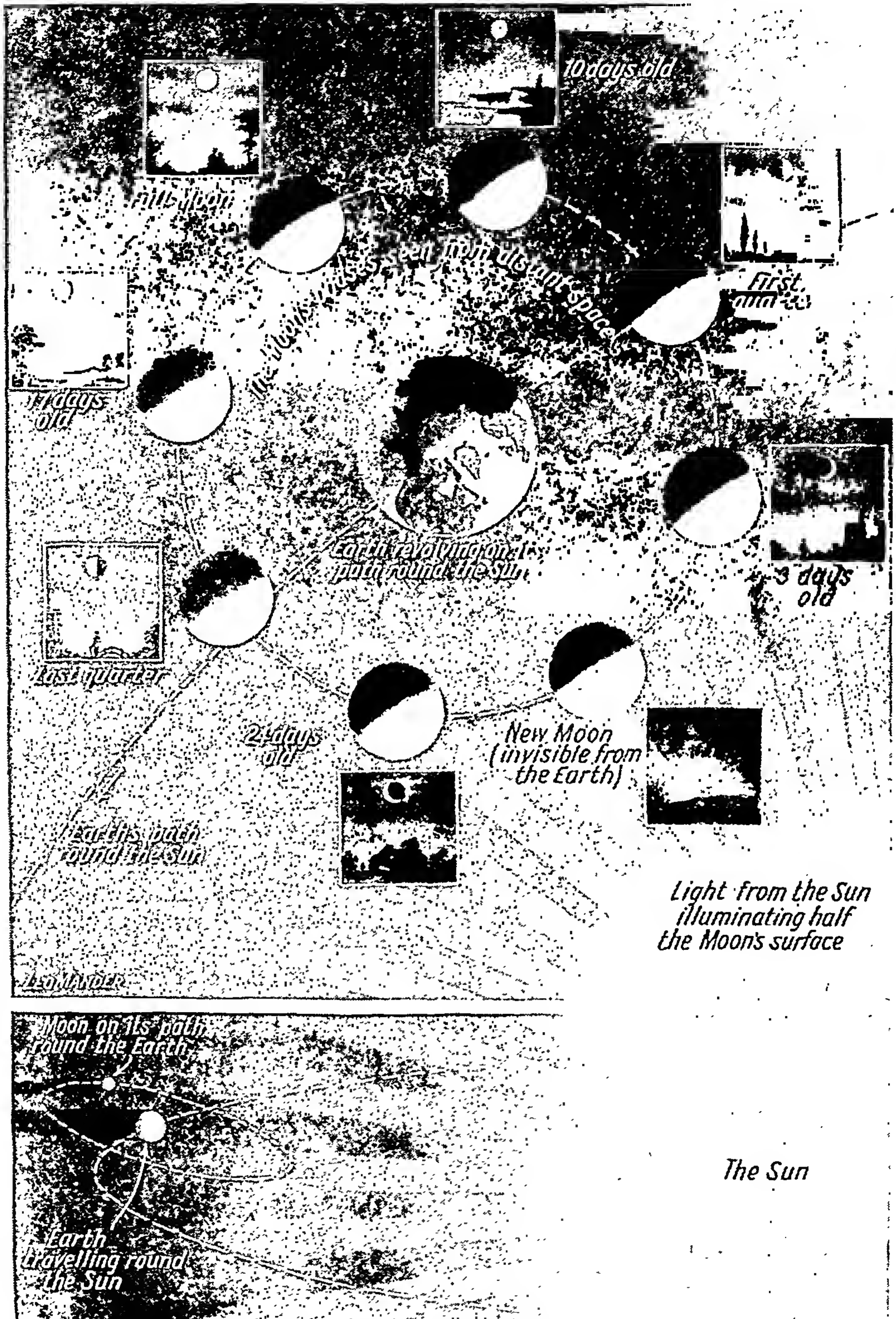


Fig. 1. The Moon in its orbit round the Earth, showing how the phases are caused.

CHAPTER 2

THE MOON

ALTHOUGH the Sun and the Moon both *seem* to have the same diameter when seen in the sky, this is only an illusion. We have seen that the Sun is an enormous body situated at a great distance from the Earth. On the other hand the Moon is comparatively small, having a diameter of only about 2,160 miles—about one quarter that of the Earth. It is situated only about 239,000 miles distant, and is, in fact, the nearest of all the heavenly bodies, being very close to the Earth as astronomical distances go. The Moon is said to be the Earth's satellite, a word coming from the Latin *satelles*, an attendant.

Exactly as the Earth revolves around the Sun in a year, so the Moon revolves around the Earth in a "moonth" or month—or, to be strictly accurate, in 27 days 7 hr. 43 min. 14 sec. Its motion from west to east must not be confused with the daily motion from east to west of all the heavenly bodies. This latter motion arises from the rotation of the Earth on its axis and causes the Sun, Moon and stars to rise and set.

We can only see one hemisphere of the Moon. No one has ever seen the other "side" of our satellite—what it would show is one of the great mysteries of Astronomy. To explain more clearly why it is that the Moon always presents the same face to us we may take the example of a horse that canters around the ring at a circus. The ring-master is in the position of an inhabitant of the Earth, for although the horse is making a complete revolution around him he never sees its off-side. What may appear to him to be an all-white horse may, for all he can tell, have a large dark patch on the off-side. On the other hand, a spectator outside the ring will see both sides of the horse, exactly as anyone standing on one of the outer planets would see both sides of the Moon.

The "phases", or variations in the appearance, of the Moon—crescent, quarter, full, and so on—greatly troubled the ancients. In fact, to explain them correctly would trouble many intelligent people to-day. Yet the ex-

Fig. 2. How the new Moon looks when it is a crescent, 5 days 23 hours old.

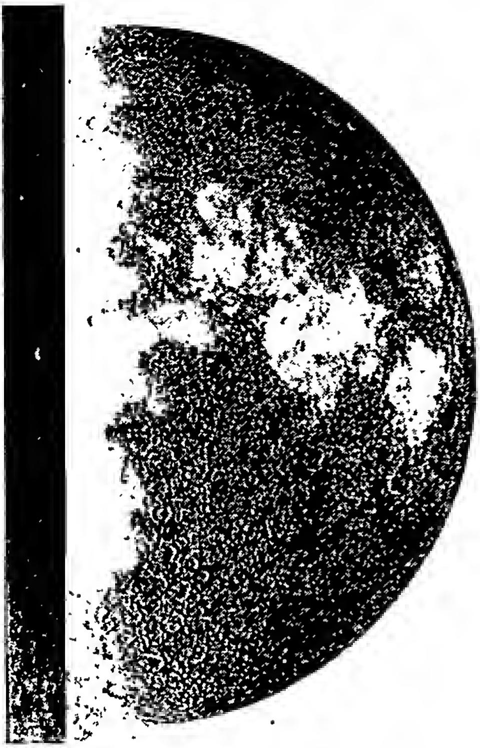


Fig. 3. The nine days old Moon.

The Moon has no illuminating power of its own, such as the Sun possesses. It shines by reflecting sunlight, and its phases are merely caused by the different position from which we on the Earth view the illuminated portion of the Moon's surface. Fig. 1 will make this clear.

When we first see the "new" Moon in the west it appears as a thin crescent, that gradually increases in size until it is "half" full, or in the "first quarter" as it is called (Fig. 2). The illuminated portion grows night by night (Fig. 3) until it becomes three-quarters illuminted, when it is known as "gibbous". Ultimately the whole of the hemisphere that is turned towards us is illuminated, when the Moon is said to be "full" (Fig. 4). It is then roughly opposite to the Sun, so the Sun, Earth, and Moon lie in one plane. The three bodies seldom lie in an exactly straight line. Whenever they do the Earth's shadow causes

planation is quite simple. The Babylonians even supposed that our satellite had a bright and a dark side, and that as it moved through the sky it gradually turned the bright side towards the Earth, until at full Moon, they thought, the whole of it was seen. Of course, this is not the explanation, for as in the case of the Earth, the Moon is a completely dark body and is composed of the same materials. Indeed, as we shall shortly tell, it is believed that once the Moon actually was part of the Earth, from which it was violently torn off in very remote times.

Fig. 4. The Moon just past the full. Notice the mysterious bright "rays" that can be seen radiating from the craters.

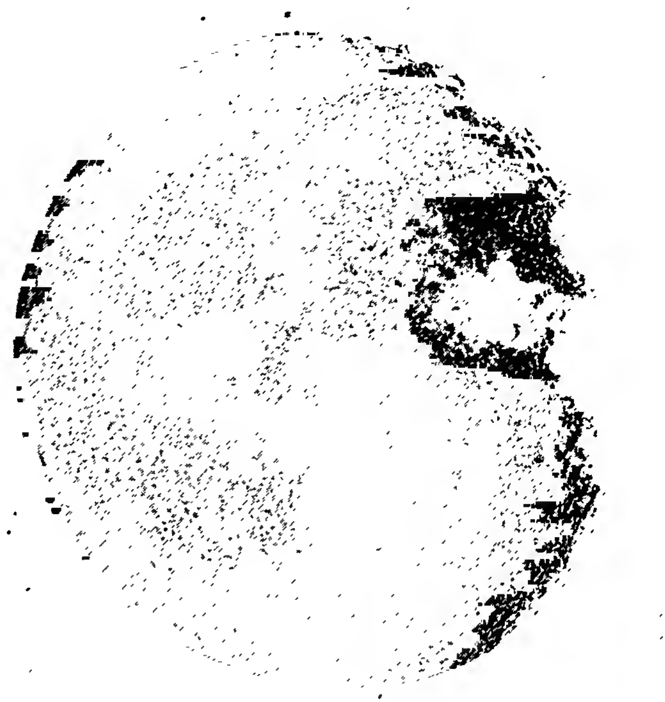


Fig. 5. The illuminated area of the Moon at 16½ days. Compared with Fig. 4, it is markedly decreasing.

an eclipse of the Moon.) Thereafter, the reverse process sets in and the illuminated portion commences to decrease in size (Fig. 5) as the Moon works its way towards the Sun. It passes successively through gibbous, last quarter, and crescent, until it moves between the Earth and the Sun, to start the cycle again as a new crescent Moon.

As the Moon grows from new to full it is said to be "waxing", and after full, it is said to be "waning". It should be mentioned that the waning crescent is opposide in shape to the waxing crescent. The curve of the crescent always points to the setting or rising Sun—as though the Moon were a bow shooting an arrow at the Sun (Fig. 6). That some people do not realise this is evident from the fact that artists have painted pictures (from imagination) in which the new Moon appears with the crescent pointing in many directions quite impossible in reality.

THE MAN IN THE MOON

Everyone has heard of "the Man in the Moon" and from very early times the dark markings to be seen with the naked eye have been likened to a man's face. Indeed, as a popular belief the legend that the man was put there for gathering sticks on a Sunday goes back to very ancient times. The "Lady in the Moon" is a more modern fancy and can best be seen when the Moon is about three-quarter full. Those possessing a fanciful imagination may be able to see several other figures. These include the "girl reading a book", "the crab" and "the donkey" (Fig. 7). Some have even discovered a "French poodle" that sits on his haunches and is correctly trimmed even to a distinct "pom-pom" at the end of his tail!

At one time the dusky markings that help to form the pictures we have just mentioned were supposed to be the reflection from the mirror-like surface of the Moon of the oceans and continents of the Earth. Looking at the Moon with his telescope (in 1610) Galileo saw for the first time that the markings were actual configurations on the Moon itself. He came to the conclusion that the large dark patches were lunar seas, and this is why they came to be called by the Latin name *maria*. To each of these "seas" was given a name that was thought to be in keeping with its appearance, such as

Mare Serenitatis, "the Sea of Serenity", *Mare Imbrium*, "the Sea of Showers" and so on. These so-called seas have a great expanse, *Mare Serenitatis*, for example, being 433 miles from north to south, and 424 miles from east to west. *Mare Imbrium* measures 750 miles by 700 miles, and covers the huge surface area of 340,000 square miles.

THE MOON THROUGH A TELESCOPE

As seen through a telescope (Figs. 2–5) we can see that these markings certainly do appear to be smooth and ocean-like, and we do not wonder that the astronomers of three centuries ago supposed them to be seas. In the light of later knowledge, however, we know that there is no water on the Moon and that although the *maria* may have been lunar seas at one time, it is certain that to-day they are nothing but great, desolate and lifeless plains.

A pair of field glasses is sufficient to show us that there are numerous ring like objects scattered over the surface o the Moon, and even a small telescop shows these objects to be very numerou (Figs. 2 and 3). They are the famou "crater rings", many thousands i number and varying in size from thos as large as Vesuvius to the grea Copernicus, with its multiple centr mountain, consisting of seven peaks, an 50 miles in diameter (Fig. 8). Eve taking into consideration the increase height of the lunar mountains—to whic we shall refer shortly—it has bee calculated that if a person were to stan in the centre of one of the great luna plains, the mountains forming the wal would be below the horizon, owing t the considerable curvature of the Moon' surface.

Each crater is named, some bein called after famous astronomers suc as Copernicus and Grimaldi; others afte ancient philosophers, as Plato an

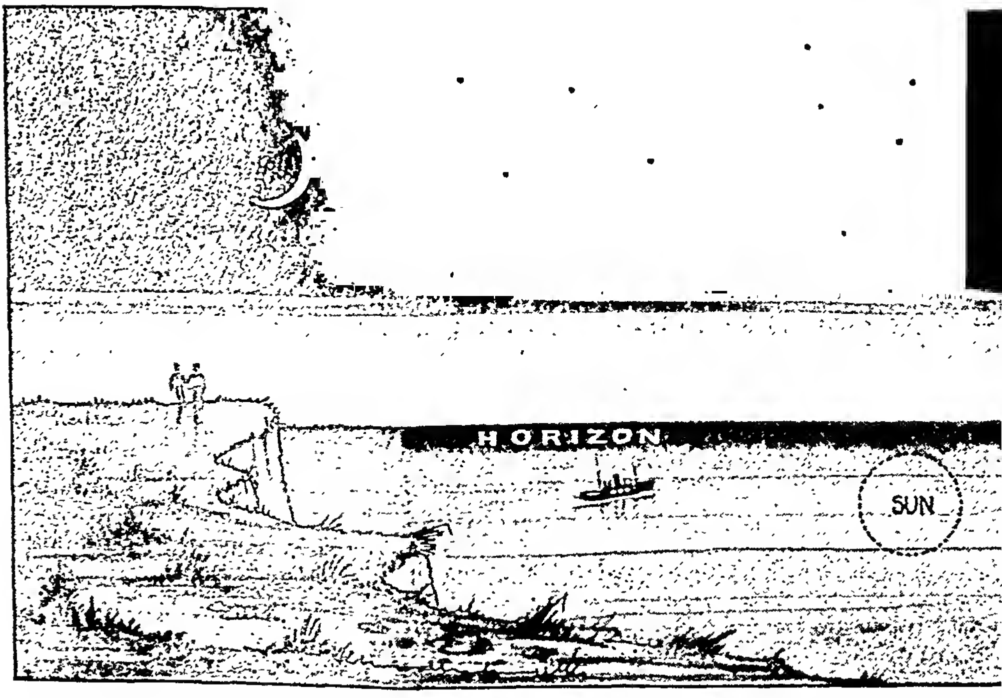


Fig. 6. The curve of the crescent Moon always points towards the Sun (shown here in outlir on the right below the horizon) because the crescent is, of course, the side lit up by the Sun.

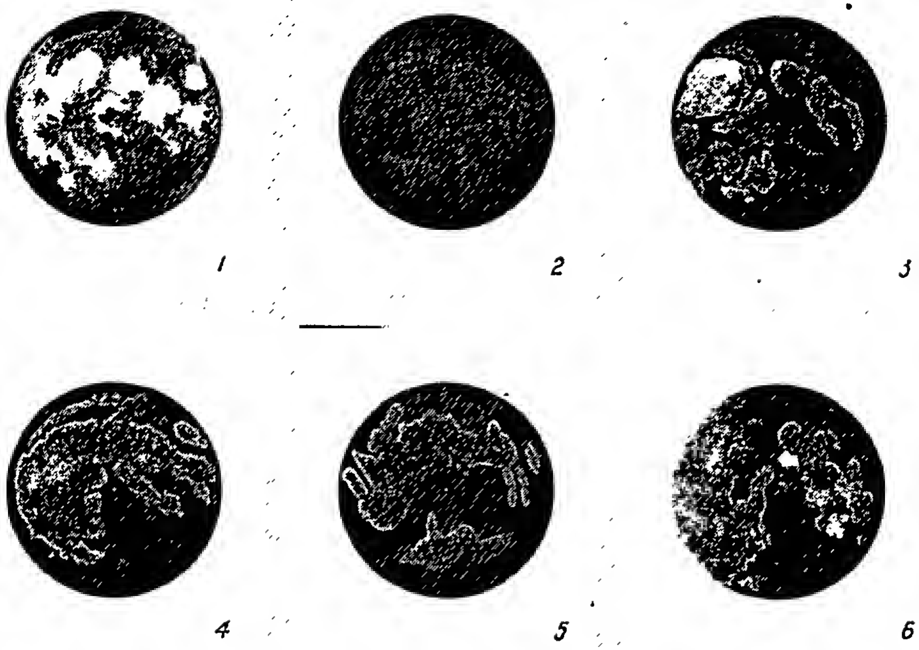


Fig. 7. The various figures that are popularly seen on the Moon. (1) The Moon as an astronomer sees it through a telescope. (2) The Man in the Moon. (3) Crab. (4) Girl reading book. (5) Donkey. (6) Lady. The artist has of course exaggerated the figures to make them clearer.

Eratosthenes. Over 30,000 of these craters have been recorded carefully on maps, down to the smallest detail—even to cracks and rills that cross them. Indeed, it has been said with truth that we know the surface of the Moon better than we know some parts of the surface of the Earth. There are parts of Africa and Brazil that have never been explored or mapped, and on the other hand, on any clear night our large telescopes enable us to study the Moon's surface as from an aeroplane flying at a height of 240 miles above it. From this distance any object the size of St. Paul's Cathedral would be visible as a tiny dot. With the new 200-in. telescope, on Mount Palomar, we shall be able to see any object the size of a small house. On this assumption, if the island on which stands the famous statue of Eros, in Piccadilly Circus, London, were on the

Fig. 8. The crater Copernicus is 50 miles in width.

Moon we should be able to see it!

In addition to the lunar cráters there are several magnificent mountain ranges, some of which are named after similar ranges on the Earth—the Alps, Caucasus, Appenines, Carpathians, and so on.

MOUNTAINS ON THE MOON

It has been found possible to determine the heights of the lunar mountains by measuring the length of the shadows they cast, exactly as the height of a flagstaff or mast of a wireless aerial can be worked out by simple trigonometry. It has been found that though none of the lunar mountains are as high as Mt. Everest, their height in relation to the Moon's size is far greater than the Earth's mountains in relation to the Earth's size. As we have seen, the diameter of the Moon is about one quarter that of the Earth—actually 2,160 as compared with the Earth's 8,000 miles and its mass about one-eightieth that of the Earth. Despite this we find that some of the lunar mountains nearly equal the height of our Himalayas. The Döerfel Mountains rise to a height of 26,691 ft.; the walls of the great crater Newton, to 23,853 ft.; and the central peak of the crater Eratosthenes, to 15,750 ft. Compared with these, our highest mountain, Mount Everest, scales 29,000 ft., Mont Blanc, 15,870 ft. and Snowdon, a mere 3,500 ft. (Fig. 9).

A more striking way of showing that the lunar mountains are comparatively much higher than the terrestrial moun-

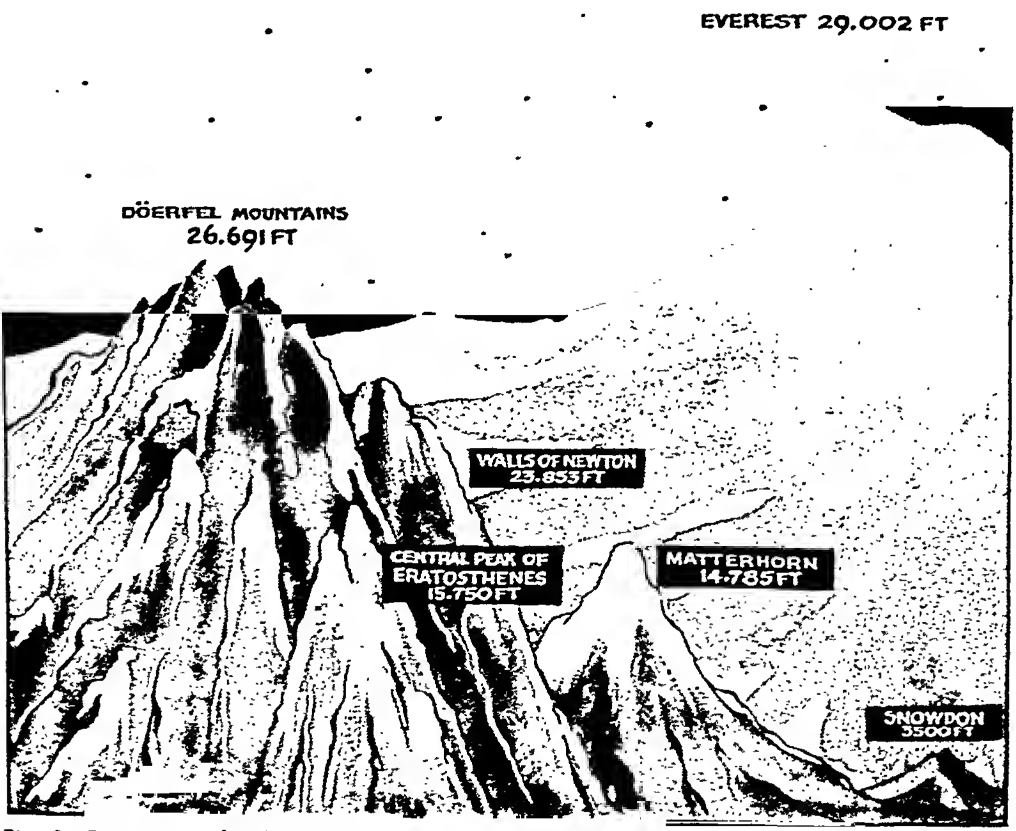


Fig. 9. Comparative heights of the mountains on the Moon and those on the Earth. The Döerfel mountains on the Moon are nearly as high as the Himalayas.

tains is to work out the relationship to the diameter. Thus, the height of Mount Everest, say, 29,000 ft., is equivalent to $\frac{1}{1140}$ of the diameter of the Earth, but the highest lunar ranges represent an equivalent of $\frac{1}{470}$ of the lunar diameter.

Here and there the lunar surface is crossed by clefts or rills, almost like the crevasses of the Alpine glaciers (Fig. 10). These cracks often extend for hundreds of miles, and are from half-a-mile to two miles in width, with a depth of up to 1,000 ft. or more. They are great chasms in the lunar surface and there is nothing terrestrial with which they can be compared. Their origin is a mystery unsolved by science.

THE MYSTERIOUS BRIGHT RAYS

Even more mysterious are the bright rays that radiate from some of the craters clearly shown in Fig. 4. Some are to be seen almost at any time, but others are seen only when the Moon is full. Why this should be we do not know. In 1900 Professor Pickering, of Harvard University, established an observatory in Jamaica to study the details of the lunar surface. He believed that alterations were taking place in the shape of some of the formations and particularly in the large walled plain called Plato. He actually came to the conclusion that the Moon is not a dead world, that it has an atmosphere, and that some of the volcanoes are still active, giving out clouds and dense gases. He believed that the strange white markings were due to hoar frost derived from frozen water vapour that had never been in a liquid condition.

We know now, however, that the Moon has neither atmosphere nor water, and in consequence fog, haze, and clouds are unknown. The absence of air and water precludes the existence of any form of life, as we understand the word.

Fig. 10. In the top right hand corner is the great walled plain, Albategnius, 80 miles across, with its mountain barrier 14,000 feet high. Numerous craters are seen below it.

Vegetation is unknown. There is no definite sign even of the lowest forms of life. All that exists is a lifeless wilderness of mountain ranges and innumerable crater rings—a barren world. Even if the existence of air and water could be proved, the extremes of temperature would make life impossible, for these vary from about 250° F. to about 200° below zero—the scorching Sun of the lunar day and the intense cold of the lunar night. The Moon affords a striking object-lesson of the fate that awaits the Earth when in the course of time it, too, will have lost its water and its atmosphere, without which essential features life will no longer be able to exist.

Both Galileo (1564–1642) and Kepler (1571–1630) suggested that the tides are

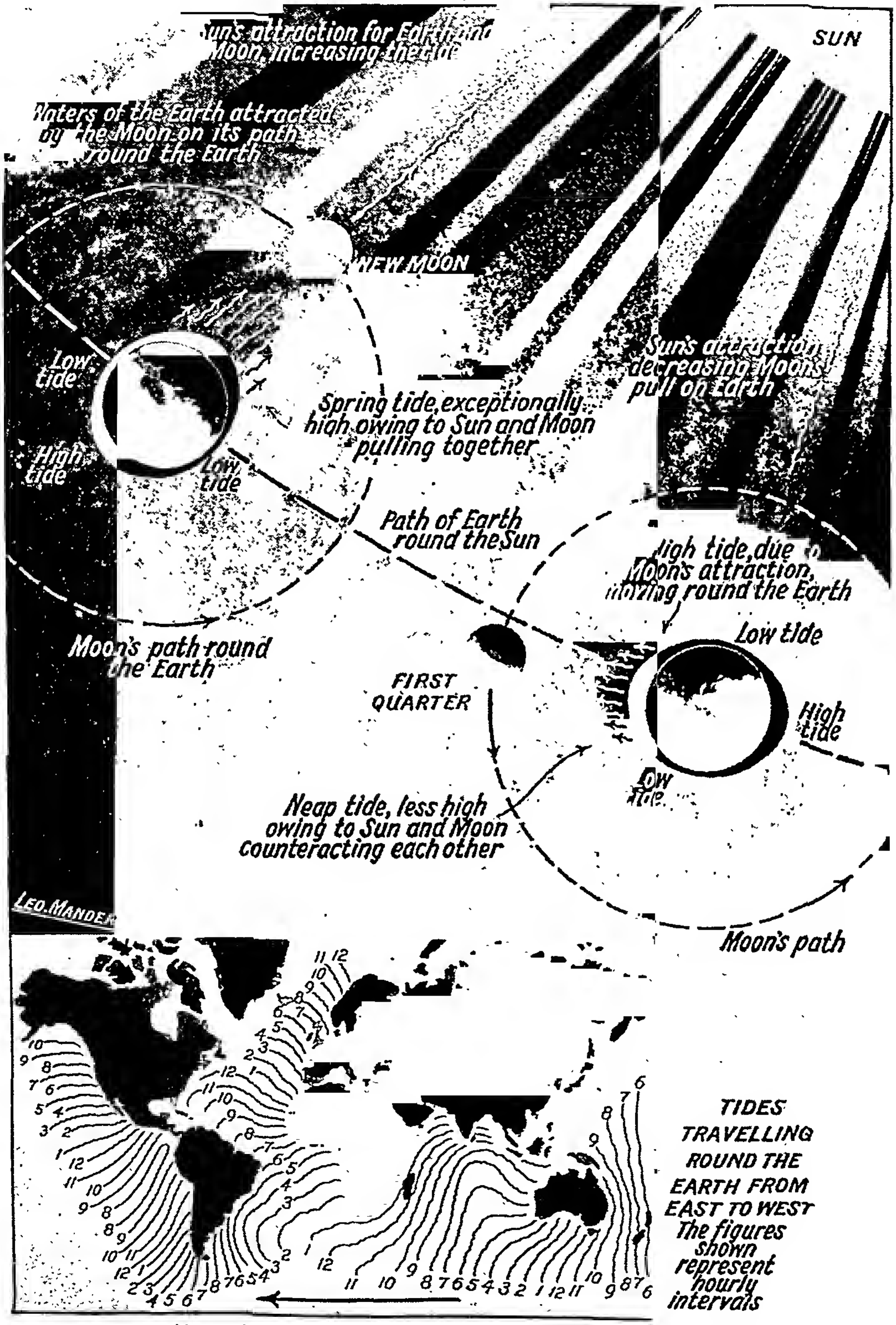


Fig. 11. How tides are caused by the gravitational effect of the Sun and Moon.

caused by the action of the Sun and the Moon. Sir Isaac Newton (1642–1727) placed the matter on a sound basis when he investigated it, and the mathematical theory was completed by Laplace (1749–1827). The Moon plays the more important part in causing the tides, thus keeping the waters in our oceans free from stagnation. The Sun also helps in this direction, but although it is infinitely larger than the Moon, as we have seen, its influence is considerably less because its distance is so much greater, and the effect of gravity, which is the force concerned, is inversely proportional to the square of the distance. This may sound rather technical, but we shall explain it at greater length in our section concerning the Earth. Actually the pull of the Moon on the water of the ocean is about three times as strong as that of the Sun.

WHY THE MOON CAUSES TIDES

Now, how can the Moon and the Sun cause tides? They do so because they act like huge magnets, pulling on the Earth (Fig. 11). The solid land is not visibly affected by this pull—it can move only as a whole—but the water on its surface is more mobile and can move independently. In other words, water readily assumes a new shape, whilst land does not. The consequence is that the water, responding to the attraction of the Moon's gravitational pull, is piled up in a heap. Twice every 24 hours throughout the Moon's revolution around the Earth the tides ebb and flow—twice the sea leaves the shore and twice it comes back. It swings to and fro in an endless succession as the Earth turns, each day bringing its waters under the influence of the Moon and Sun.

We have said that the land is not visibly affected by this pull of the Moon and Sun. Nevertheless, the land does rise up like the sea at the time of the tides, and a seismograph—or earthquake-recording instrument—is sufficiently delicate to record these minute tidal waves in the land.

We often hear the terms "spring tide" or "neap tide". Spring tides occur when the Moon, the Sun, and the Earth are in line and the two former exert a combined pull on the waters of the oceans (Fig. 11). These tides are the most marked of all—that is, at these times the high tides are highest and the low tides lowest—but the name "spring tide" is somewhat misleading, since such tides occur twice every month throughout the year when the Moon is new and when it is full. Neap tides, the opposite to spring tides, occur when the Moon and the Sun are pulling the waters in different directions—that is to say, when the Moon is either at the first or the last quarter. The result is that at these times there is least difference between high and low tide levels.

Some very interesting speculations resulted from an investigation into the tides, made by Sir George H. Darwin, F.R.S. He suggested that the constant tidal wave raised throughout the ages must be acting as a giant brake on the rotating Earth, slowing it down and ultimately increasing the length of the day until in time it will be as long as the lunar month. If this theory is correct, the amount by which the Earth is slowed down must be infinitesimal, for so far as we know the length of the day has not increased even by a fraction during the history of Man. On the other hand, we must remember that it is only during the last few hundred years that the accuracy of observation has been such as would enable the discrepancy to be detected. Even then, observations over a period of tens of thousands of years would be necessary to detect the minute quantity involved. A period of about 50,000,000,000 years is calculated

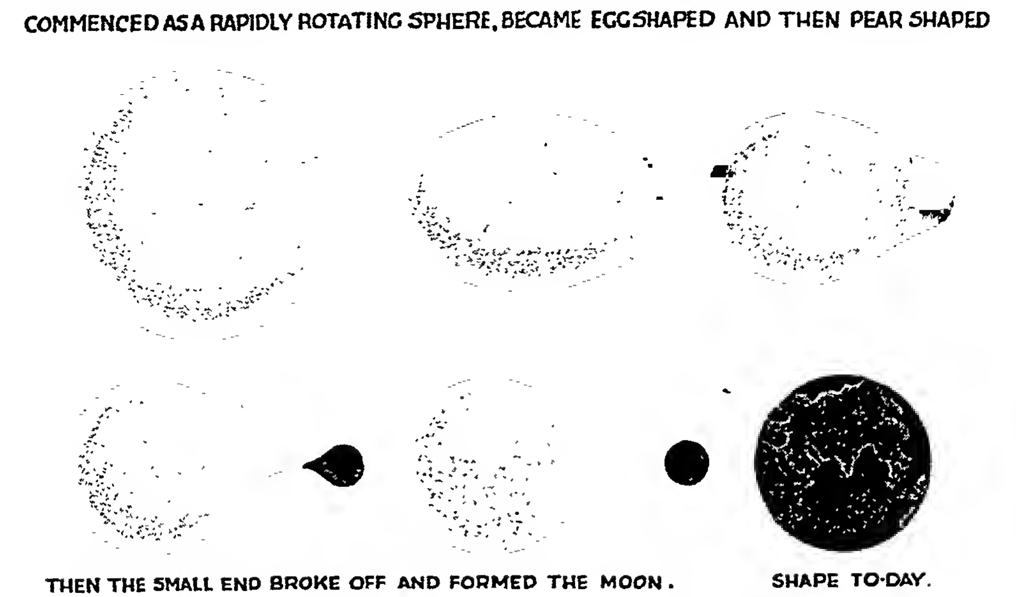


Fig. 12. One theory of how the Moon was formed. During the plastic period in the Earth's history part of it split off centrifugally to form a separate body—the Moon.

to be the time required for the Earth's rotation-period to slow down until equal to the lunar month.

Sir George has proved that the distance of the Moon from the Earth is increasing, and that therefore—in accordance with Kepler's laws of motion—its period of revolution is necessarily becoming longer. This being so, the time will come eventually when the length of the day and the month will coincide—both will last for 55 of our present days, the Moon revolving around the Earth in the same length of time as is required by the Earth to rotate on its axis. Then a reverse movement will set in, and the Moon will again draw close to the Earth until it reaches what is known as "Roche's limit", situated about 12,000 miles distant from the Earth. When that distance is reached enormous lunar "tides" will be raised by the Earth, and the Moon will be shattered to fragments. A ring of tiny satellites will be formed—similar to those that are to be seen revolving around Saturn, as will be mentioned later in the chapter on Planets.

So much for the future. Let us now look into the past, when the Earth was rotating on its axis in a very much shorter period than at present—probably about four or five hours. At that time the Moon must have been nearer to the Earth than it is to-day, and was probably revolving around the Earth in a period that coincided with the rotation period of the Earth.

Looking back still further, in time, probably there was a time when the Earth and the Moon, in a semi-gaseous or plastic state, were so close as to be in contact with one another. Before this, again, the two may have formed a single body, the rapid period of rotation of which, and the consequent enormous tides, caused the Moon to split off from the Earth. This theory, represented diagramatically in Fig. 12, suggests that at this time the denser materials of this

Earth-Moon body collected at the lower levels, whilst the lighter materials distributed themselves uniformly over the surface. To-day, there is a conspicuous absence of these lighter materials in one hemisphere, from which it is suggested that the Moon was torn off. The mass of material that formerly covered that part of the Earth where there are now no continents would correspond in density to that of the Moon. In other words—the continents of that part of the Earth now occupied by the Pacific Ocean, are to be seen high in the heavens, a quarter of a million miles distant and still slowly receding from the Earth—the parent body!

ECLIPSE OF THE MOON

An eclipse of the Moon is caused when the Moon passes through the long shadow, cast by the Earth in space (Fig. 13). As in the case of eclipses of the Sun, this does not occur every month, and for the same reason as already explained, and illustrated in Fig. 13 of Chapter I (p. 17). If the Moon revolved around the Earth in the same plane as that in which the Earth revolves around the Sun, there would be a solar and a lunar eclipse every month. As it is, the Moon's orbit does not lie in this plane, being inclined to it at an angle of just over 5°, and there are comparatively few eclipses, the number varying each year. Even in the most favourable circumstance there can never be more than seven eclipses in any one year—some times there are as few as two—and of these the numbers of solar and lunar eclipses are not necessarily equal.

An eclipse of the Moon is different in character from an eclipse of the Sun, for the obscuration of the Moon in the Earth's shadow is not a local but a general phenomenon. We have already seen that a total eclipse of the Sun is seen only from those places over which the line of totality passes, and that on either side of this restricted area the occurrence

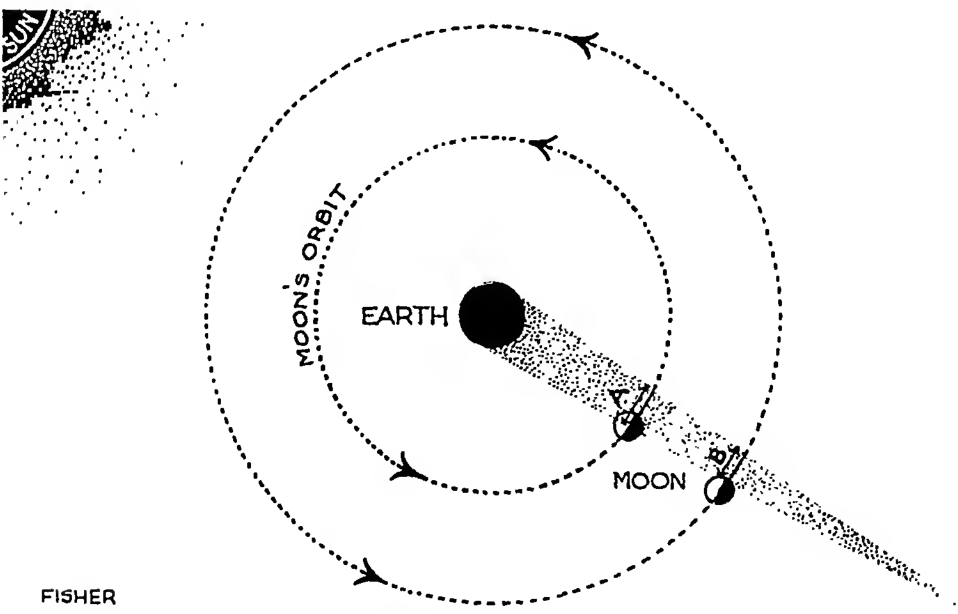


Fig. 13. As the Moon circles round, it sometimes passes through the Earth's shadow and is eclipsed. Its distance from the Earth at these times determines the length of the eclipse. Thus at A, the eclipse is longer than at B, for at A the Moon passes through a wider shadow.

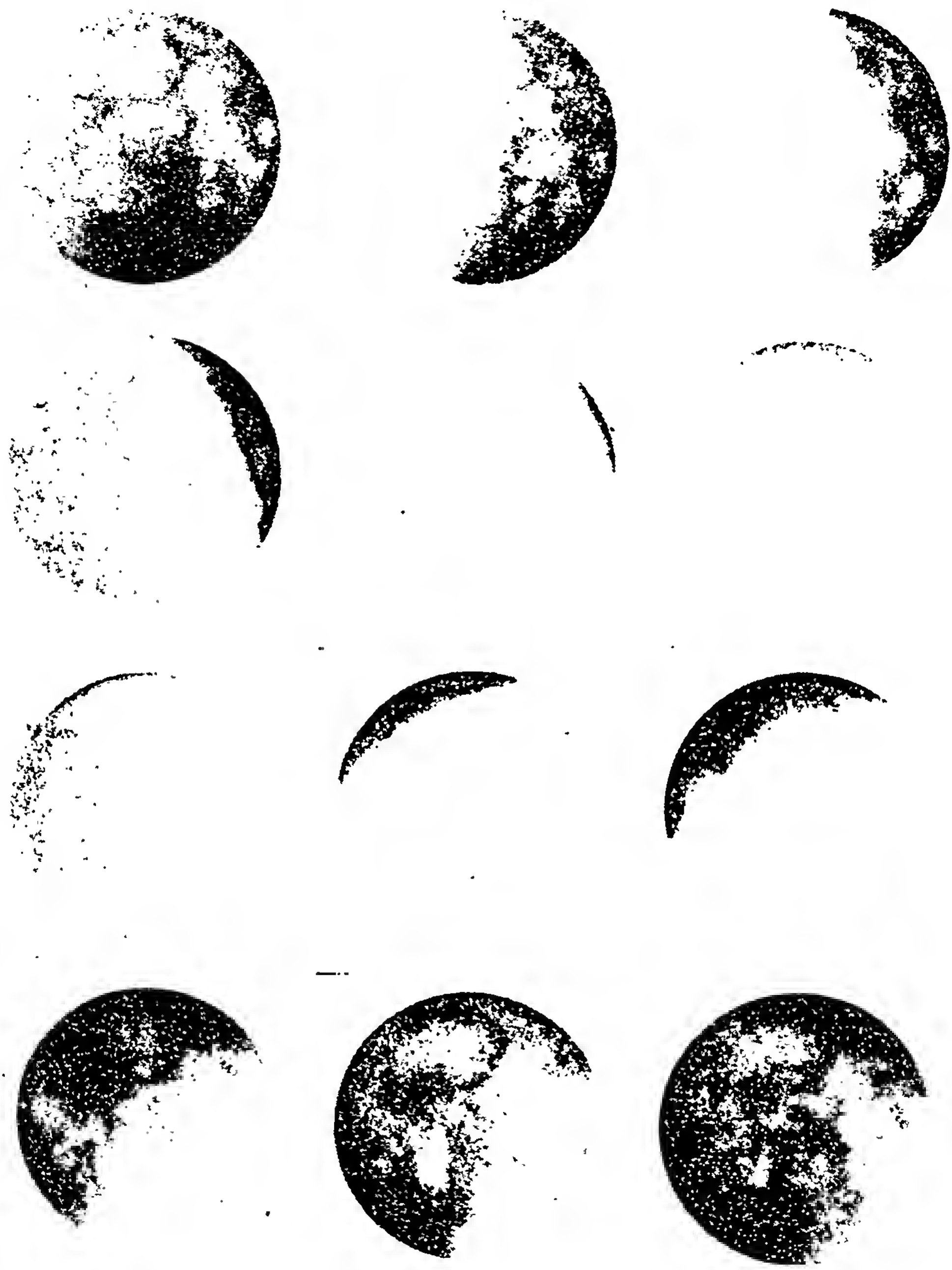


Fig. 14. A total eclipse of the Moon photographed at its various stages. The right hand photograph in Row II was taken at full eclipse, the Moon being still visible.

is seen as a partial eclipse. On the other hand, an eclipse of the Moon is visible to the same extent to people in all those parts of the Earth from which the Moon is visible at the time. To express it in another way, a solar eclipse is due to the Moon's shadow passing over certain places on the Earth, whilst a lunar

eclipse takes place in space, the shadow of the Earth being seen on the actual surface of the Moon. Eclipses of the Moon may be partial or total, the former occurring when the Moon does not completely enter the Earth's shadow. For the reasons already explained, a partial lunar eclipse is visible to everyone as a partial eclipse and a total eclipse as a total eclipse, whereas a total eclipse of the Sun may be seen as a total eclipse from some places and as a partial eclipse from others.

The shadow cast by the Earth extends into space as a great cone and reaches far beyond the orbit of the Moon. Consequently, the Moon is plunged into this shadow for a length of time that varies according to the exact distance of the Moon from the Earth at the time of the eclipse. The greater the distance, the less the diameter of the shadow through which the Moon must pass; and consequently the shorter the duration of the eclipse. This is illustrated in Fig. 13. The Moon may remain eclipsed for as long as 1 hr. 50 min.

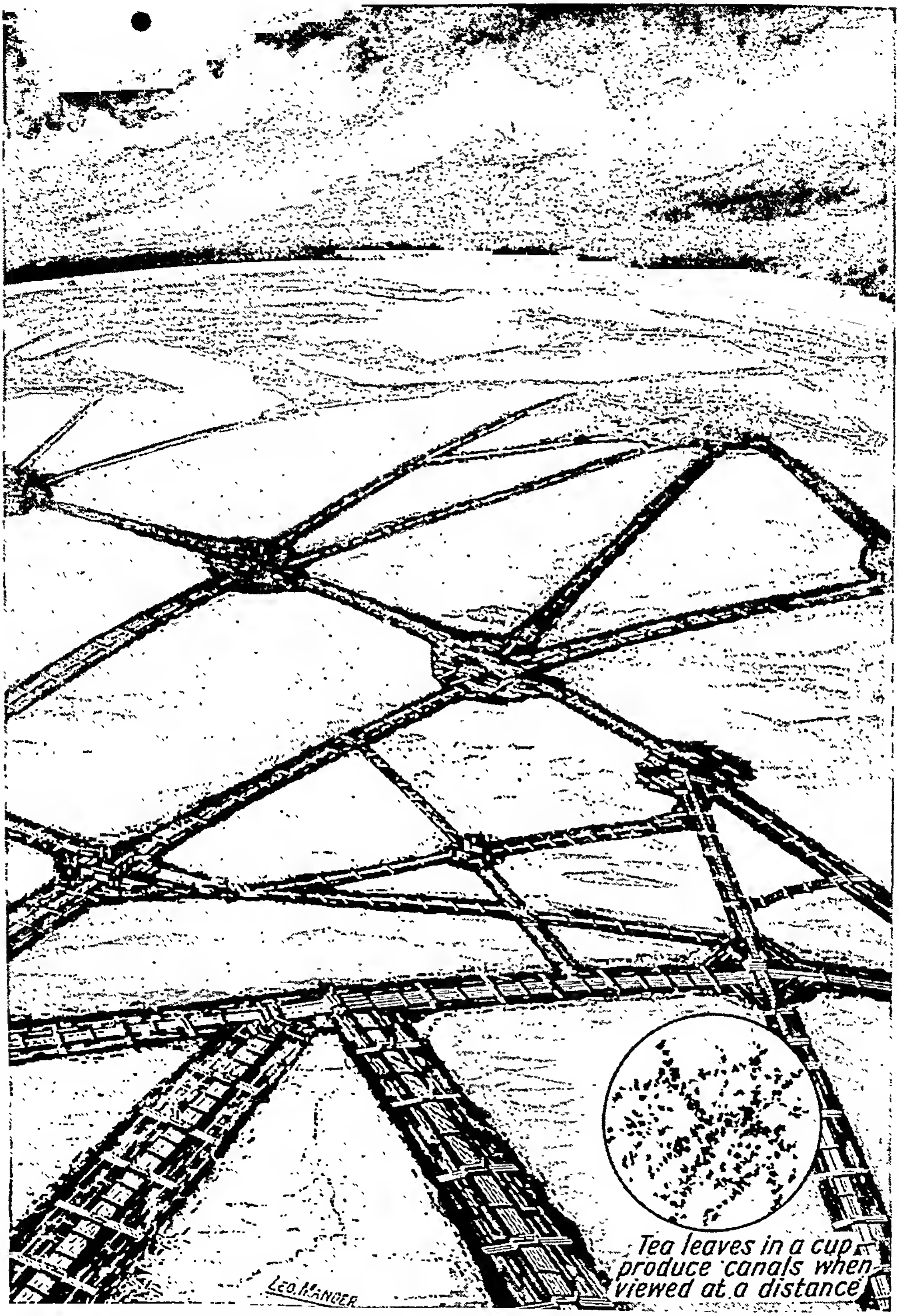
THE "GHOST" MOON

At these times, although technically said to be "completely obscured", the Moon may often be seen as a ghost of its normal self, sometimes copper-coloured, or sometimes brown or grey. This variation in the colouring is due to refraction by the Earth's atmosphere of the sunlight that falls on it from the opposite side. When the eclipse takes place, the Moon is on the dark side of the Earth, the light from the Sun falling on the opposite hemisphere. Some of this sunlight striking the edges of the Earth is refracted inwards by the atmosphere, the rays being thus caused to fall on the surface of the Moon, partially illuminating it. That the Moon, although totally eclipsed, may yet be visible is illustrated in Fig. 14 by the third photograph in the second row. As we shall learn in a later section, the amount of water vapour in our atmosphere varies from day to day, and we can understand, therefore, that the degree of refraction varies similarly, so causing a difference in colour of the eclipsed Moon as between one eclipse and another.

EARLIEST RECORDED ECLIPSE

The earliest record of a lunar eclipse is found in a Chinese book, discovered in A.D. 280 in the tomb of an emperor who had lived many centuries previously. The eclipse here referred to is probably that of 29th January, 1136 B.C. The last two total eclipses to be seen from this country were in 1936 and 1938, but observation of the former was entirely spoiled by clouds and rain. The eclipse of 7th November, 1938, was seen in most parts of the country, however, and lasted for some time. The Moon began to dim as it entered the outer shadow, or penumbra, at 7.39 p.m. and the shadow proper at 8.45. It was totally eclipsed at 9.45, and remained so until 11.8 p.m. The Moon then commenced to move out of the shadow, from which it was not entirely clear until 1.14 a.m. Even when totally eclipsed the Moon remained clearly visible, and whilst the greater part of the disc was distinctly red, the crescent round the northern limb showed scarcely any colour and was much brighter than the remainder of the disc. This indicated that while the red rays from the Sun were refracted by the Earth's atmosphere so as to spread over the greater part of the Moon's surface, the rays from the blue end of the spectrum were refracted only sufficiently to reach the northern limb and this part of the Moon was accordingly bathed in nearly white light.

This eclipse was seen from the eastern seaboard of the United States of America whilst the Sun was still in the sky.



An artist's impression of what the much discussed markings on Mars might look like on nearer view. It is, of course, quite unproved that they are in fact canals made by human or near human beings.

CHAPTER 3

THE PLANETS

Until the middle of the sixteenth century the Earth occupied a more important position in the mind of Man than it has occupied since that time. Never again will it achieve the same degree of importance. Up to that time it was believed that the Earth was the centre of the universe and that the Sun and all the heavenly bodies revolved around it. To-day, every schoolboy knows that far from being the centre of the Universe, as Ptolemy taught, the Earth is not even the centre of that particular part of the universe to which it belongs. It is merely a planet that circles around the Sun in company with eight other planets, some of which are enormously greater in size than the Earth. Dethroned from its proud position, it is seen in its true light—a speck of solidified gas—a nonentity in the vast cosmos, and apparently of about as much importance in the celestial scheme as a single grain of sand on the Sahara desert.

THE SOLAR SYSTEM

The Earth and its fellow planets, together with a number of minor bodies such as comets and meteors, form the solar system (Fig. 1). The planets have no light of their own and shine only by reflecting the light of the Sun, exactly as does the Moon. Each planet moves around the Sun in a regular, mathematically calculable path, or orbit. Those nearest to the Sun complete a circuit in a comparatively short time; those further away take longer.

Fig. 2 illustrates approximately the comparative size of the planets, as compared with the Sun, the size of which in the diagram is represented by the equatorial section below the planets. We are better able to visualise the relative sizes and distances separating the Sun and the Earth if we imagine a model in which the Sun is represented by a 9-ft. globe. On the same scale the Earth would be represented by a ball 1 in. in diameter at a distance of nearly

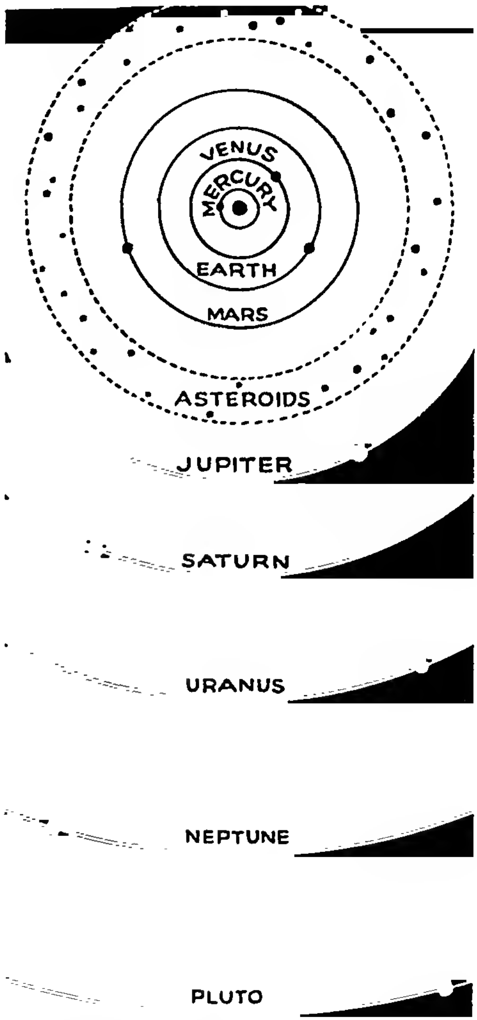


Fig. 1. The Solar System. Neither the planets nor their orbits have been drawn to scale.

1,000 ft. Between the orbit of the Earth and the Sun are the orbits of two other planets, Mercury and Venus. They would be respectively represented in our model by a large pea 380 ft. distant and a 1-in. ball at a distance of 700 ft. from the 9-ft. globe representing the Sun.

Mercury, the planet nearest to the Sun, is the smallest planet and completes one revolution of its orbit in about 88 days. We do not often see Mercury, for as it is never at a greater angle than 28° from the Sun (in relation to the Earth) it is generally overpowered by the brightness of the sunlight. The best times to see it are in the evenings in spring and in the early mornings in the autumn. Despite this difficulty of observation, Mercury was well known to the ancients. It was called "the Sparkling One" by the Greeks; Chinese astronomers observed it as early as A.D. 118; and even earlier allusions to it were made by the astronomers of Nineveh in a report they made to Assurbanipal, King of Assyria.

Mercury is believed to rotate on its axis in the same period of time as it revolves around the Sun, namely 88 days. Thus, it always presents one face to the Sun, so that one side of the planet is in perpetual light and the other in perpetual darkness. On that side facing the Sun, the temperature must be about 350° C.—or more than enough to melt lead—whilst on the other side it must be extremely cold, because there is no atmosphere to circulate heat from the illuminated side. There can be no life on Mercury—as Professor Lowell has said, the planet is merely "the bleached bones of a world".

WHY VENUS IS SO BRIGHT

Between the orbits of Mercury and Earth lies that of the planet Venus, which revolves around the Sun in about 255 days. Unlike Mercury, Venus is easily seen and often is so bright that general attention is called to it, letters to the papers frequently asking about "the extraordinarily bright star seen in the sky last night". The particular brightness of Venus is caused by the fact that the planet itself, which is about the same size as the Earth, is surrounded by a dense atmosphere that reflects a large proportion of sunlight. This cloud envelope makes it difficult for us to see anything beneath, however, and beyond a few dusky markings nothing is known of the planet's surface, but it is believed that the planet rotates on its axis in about three days.

Because Mercury and Venus lie between the Earth and the Sun it follows

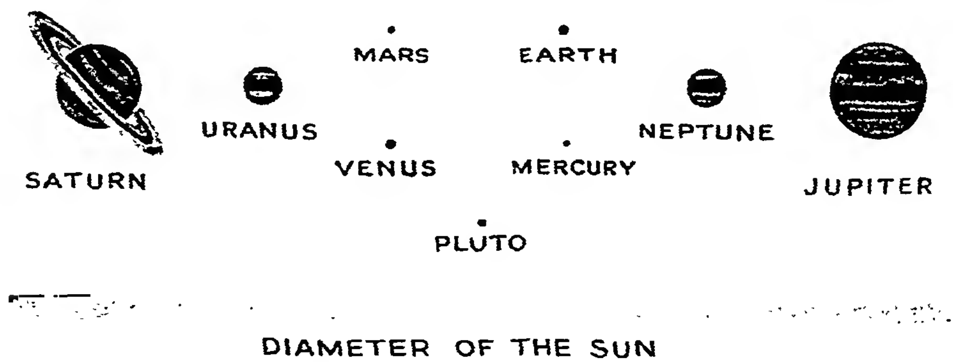


Fig. 2. The comparative sizes of the nine planets of the solar system.

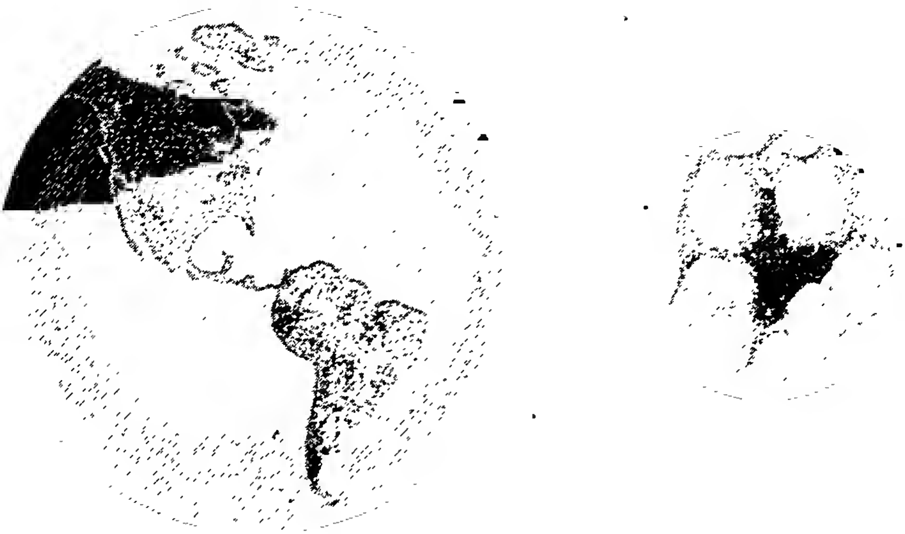


Fig. 3. The comparative sizes of the Earth (diameter 8,000 miles), and of Mars (diameter 4,230 miles).

that in the telescope these planets will exhibit phases, just as the Moon does. Thus we may have a "new" or "half" Mercury, a gibbous or a crescent Venus, depending on the relative positions of the Sun, the Earth and the planets.

MARS AND ITS MYSTERIES

Beyond the orbit of the Earth is that of Mars, perhaps the best known of all the planets, because of the mysterious markings—the so-called canals—that have been seen on its surface and the suggestion that the planet may be inhabited by intelligent creatures. As the diameter of Mars is 4,230 miles, it is a little over half the size of the Earth (Fig. 3). In our model it would be represented by a marble ($\frac{1}{2}$ in.) at a distance of 495 yards from the 9-ft. Sun. Actually its distance from the Sun is about 141,000,000 miles, and it completes a revolution in its orbit in 687 days. Thus the "year" and the seasons on Mars will be nearly twice those on the Earth.

Unlike Venus, no clouds obscure the Martian surface. The telescope shows dusky markings that persist year after year, suggesting that they are permanent features of the Martian landscape (Fig. 4). We can see that the surface of the planet is practically level, mountains being unknown, and that at the poles are white patches that increase and diminish

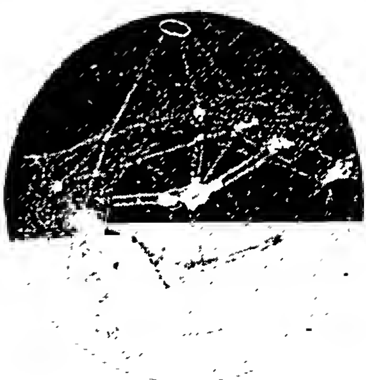


Fig. 4. Mars as drawn by Professor Lowell. At the top is the South polar cap and the surface of the planet shows distinctly, several "canals."

Fig. 5. Mars and its tiny satellites, Deimos and Phobos. Note the Polar cap and the "canals."

with the Martian seasons. These are the Martian polar caps, composed of ice and snow and analogous to our own Arctic and Antarctic regions. They have been carefully observed over many years. Sometimes great chasms have been noticed in the southern polar cap, portions of which have become detached at the breaking up of the ice and snow with the advance of the Martian summer.

The deposits of ice and snow in the polar regions are less than those on the Earth, and sometimes they disappear entirely. During the summer the dark markings are generally of a greenish colour, presumably due to vegetation, since they change to russet brown with the approach of autumn on the planet. The remainder of the surface is the orange yellow of a sandy desert, looking exactly as we would expect the Sahara or the great Arabian desert to appear if seen from a similar distance.

Undoubtedly Mars has an atmosphere, though it is at the best a rarefied one, and the spectroscope has shown that it contains the aqueous vapour that—as we shall see in a later section—is so necessary to life. The climate would appear to be very mild. The surface of the planet has been closely studied over many years by many observers. Maps have been made, together with thousands of drawings and hundreds of photographs, showing the planet under all conditions year by year.

THE CANALS OF MARS

In 1877, G. V. Schiaparelli, Director of the Milan Observatory, found that many of the dark markings are joined together by a network of fine lines. It is these mysterious markings—the "canals"—that have caused so much discussion (Fig. 4). The canals appear always to run in straight lines, taking the shortest route from point to point. They maintain a uniform breadth of about six miles, and vary in length from a few hundred to 3,000 or 4,000 miles. The late Dr. Percival Lowell, who built

an observatory at Flagstaff, Arizona, U.S.A., specially to study Mars, believed that the canals are of artificial origin and that they have been made by the inhabitants of Mars to lead water from the melting polar caps through the Martian deserts.

The reason for the prodigious enterprise of this complicated canal system (if such it is) is found in the fact that as there are no mountains and no clouds on Mars there can be no rain, and consequently no rivers. If the planet is inhabited, the Martians must grow vegetable food for their subsistence. In view of the permanent water famine, water must be brought from the melting polar caps to irrigate the Martian deserts with the semi-annual unlocking of the polar snows. What we see are not the actual canals but the vegetation that grows in the desert area through which they run. Could we look back at the Earth from Mars we should see very much the same thing taking place after the yearly inundation in the Nile Valley.

It is only fair to say that there are others who do not support this interesting theory. They think all those observers who have seen and drawn the canals are suffering either from an optical illusion or a vivid imagination! Others again think the strange markings are merely rifts in the surface of the planet, caused by the cooling of the globe. There is no question, however, that these strange markings do exist—the argument is as to their actual nature and significance. One obstacle that has to be overcome by those who disbelieve the canal theory is the fact that the canals are undoubtedly connected with the Martian seasons. They disappear in the winter and reappear in spring and summer, behaving, indeed, exactly as they would if their appearance was due to the growth of vegetation brought to life by the water that is released from the polar caps in spring and summer.

As a result of his work, Percival Lowell was convinced that Mars is inhabited by beings of some kind or another, but it is uncertain in exactly what form these beings may exist. The theory of the existence of intelligent life on Mars, Lowell said, may be likened to the atomic theory in chemistry in that in both we are led to believe in units that we are unable to define. Both theories explain the facts in their respective fields and they are the only theories that do, but we can no more say what an atom may resemble than we can be certain what a Martian may be like. The behaviour of the chemical compounds points to the existence of atoms too small for us to see, and in the same way, the aspect and behaviour of the Martian markings implies the action of agents too far away to be discerned.

THE SATELLITES OF MARS

Mars has two tiny satellites, named Deimos and Phobos, discovered in 1877 (Fig. 5). The former is only 10 miles and the latter 36 miles in diameter. They afford some idea of the excellence of modern telescopes, for their size and distance when observed from the Earth is comparable to that of two apples hung over the city of Edinburgh and observed from York.

Jupiter is the largest planet of the solar system, and sufficiently large to contain more than 1,000 planets the size of the Earth. It is nearly 88,000 miles in diameter and is situated at a distance of about 483,000,000 miles from the Sun, requiring 12 years to complete one revolution. Taking our earlier illustration, Jupiter on the same scale would be represented by an 11-in. globe situated a mile distant from the 9-ft. globe which represents the Sun.

Fig. 6. Jupiter showing characteristic cloud belts lying parallel to its Equator. Note its distinctly oval outline combined with the marked flattening at the Poles.

As seen in the telescope, Jupiter is distinctly flattened at the poles (Fig. 6). Actually this flattening, which amounts to about $\frac{1}{16}$ of the whole, is due to two facts: first, that the planet is not yet completely solidified, and second, that it rotates on its axis in the incredibly short space of less than 10 hours. The planet's surface is crossed by alternate light and dark belts, which on close inspection are seen to be composed of clouds (Fig. 6). Although constantly altering in appearance, they always lie in well-defined parallel zones, which for purposes of identification are named after the corresponding zones on the Earth.

Although, as a rule, the details of the cloud belts are constantly changing, there is in the South Equatorial Belt a peculiar spoon-like marking, called the Great Red Spot, that seems to be of a more permanent nature (Fig. 7). First observed in 1665, it has been recorded through the intervening years and in recent times has been the object of close study by many observers. This mysterious feature, which measures some 30,000 miles in length and 7,000 miles in breadth, has been described as varying from a full brick-red colour to rose-pink. It is situated in a kind of bay called the "Hollow", which is so clearly defined as to be visible even in a small telescope. The Red Spot was exceptionally prominent in 1918–19 and again in 1936, and on both these occasions the Hollow became correspondingly faint. No satisfactory explanation has yet been put forward to account for this peculiar feature. In the early days it was thought that it might be the mouth of some huge volcano, rearing its head above the clouds that lie above the surface of the planet. This was later shown to be impossible, however, for it was found that the Red Spot has a proper motion of its own—that is to say, it

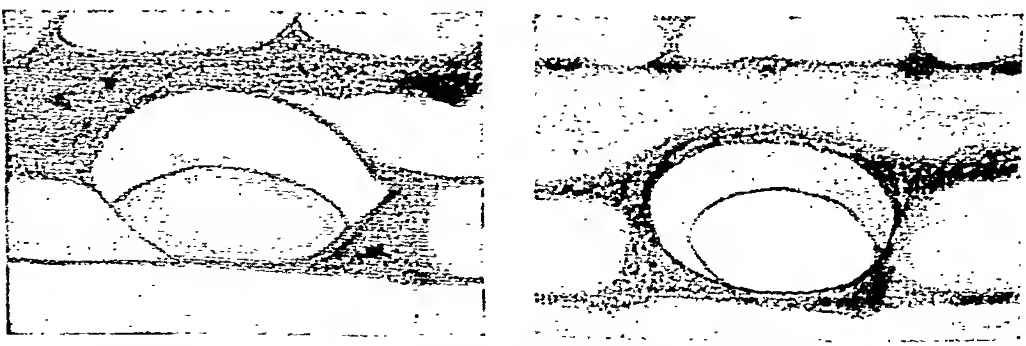


Fig. 7. Two views of the mysterious Red Spot of Jupiter showing the well known "Hollow." In the left drawing, the almond shaped Red Spot is more prominent; in the right, the "Hollow" is more noticeable. These markings are not yet fully understood.

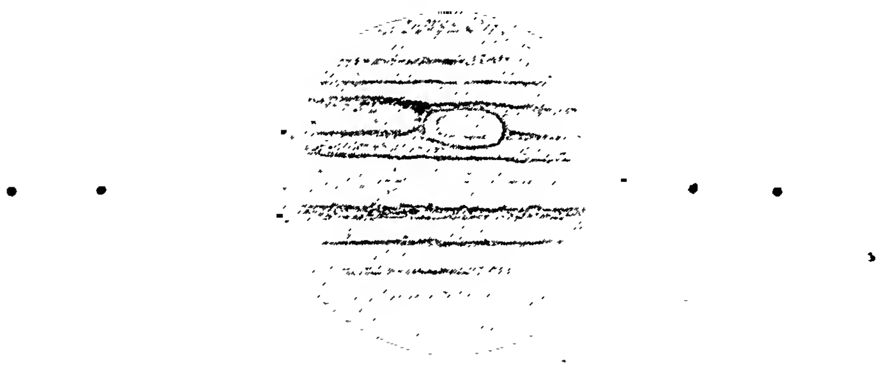


Fig. 8. Jupiter with four of its principal satellites. Besides these four moons, which were discovered by Galileo, Jupiter has five other satellites. The Red Spot and Hollow can also be seen.

moves on its own account as well as partaking in the general axial rotation of the planet. Whereas the average time for the rotation of the Equatorial Zone is 9 hr. 50 m. 30 sec., and for the Temperate Zone 9 hr. 55 min. 40 sec., the rotation period for the Red Spot is 9 hr. 55 min. 37 sec. The most probable explanation of this mysterious object is that it is actually a new satellite in the process of formation—some great continent, perhaps, torn off from the surface of the planet, precisely, indeed, as is believed to have occurred in the origin of our own satellite, the Moon.

JUPITER'S NINE SATELLITES

Jupiter is already rich in satellites, having no less than nine. The four principal ones (Fig. 8) were discovered by Galileo and used by him as an illustration to support the Copernican theory that the Earth revolves around the Sun. These four satellites—the largest of which, Ganymede, is 3,550 miles in diameter—present a succession of interesting phenomena. As they pass behind the planet they are "occulted", that is, concealed. Again, when they pass into the great shadow cast by Jupiter in space, they are eclipsed exactly as our Moon is eclipsed when it passes into the Earth's shadow.

It is rather remarkable to find that the outermost satellites revolve round Jupiter in a retrograde direction—that is to say in a direction contrary to that generally followed by their fellow-satellites and by the satellites of the other planets. For this and other reasons it has been suggested that these bodies are not genuine satellites but minor planets that have approached too close to Jupiter and been drawn into its system by the effects of gravitation.

Saturn, the planet beyond Jupiter, is regarded by many as being the most beautiful object that can be seen through the telescope, because of the vast system of "rings" that encircles it (Fig. 9). Its size, in comparison with a 9-ft. globe representing the Sun, is that of a 9-in. globe at a distance of $1\frac{3}{4}$ miles. Actually its diameter is 73,000 miles, its distance from the Sun being 886,000,000 miles.

Galileo was puzzled by the appearance of the planet as seen in his small and imperfect telescope. When he first observed it, the planet appeared to him as though accompanied by two smaller

Fig. 9. The beautiful planet, Saturn, surrounded by its ring system.

"stars" on opposite sides. Later, he was surprised to find that the two smaller "stars" had disappeared and that Saturn was but a single globe. Very perturbed at this, and thinking he had made a mistake in his previous observation, he wrote: "Are the two lesser stars consumed after the manner of the solar spots? Have they vanished or suddenly fled? Has Saturn, perhaps, devoured his own children? Or were the appearances indeed illusion and fraud? I do not know what to say in a case so surprising, so unlooked for, and so novel. The shortness of the time, the unexpected nature of the event, the weakness of my understanding, and the fear of being mistaken, have greatly confounded me".

Fig. 10. Three views of Saturn's rings. At top, the rings edgeways on, are almost invisible.

It was not until some years later that the explanation of these curious changes was discovered, when Huygens came to the conclusion that Saturn was surrounded by a flat ring-system. This, he concluded, is inclined to the ecliptic—the great circle on the celestial sphere along which the Sun apparently travels during the year—and nowhere touches the body of the planet. The "rings" vary in their aspect because of the alteration of the angle at which they are tilted towards the Earth (Figs. 10 and 11). Thus it is that we sometimes see a broad expanse of ring that gradually decreases as the angle becomes less acute.

Ultimately a point is reached when the "rings" are "edgeways-on" to us, and at this time they are practically invisible, as shown in the top illustration of Fig. 11. They run through this cycle of changes in 30 years. Galileo's telescope was not powerful enough to distinguish the "ring" in any essential details, as already explained. What he thought were two stars were the portions of the "ring" seen on either side of the globe of the planet itself.

WHAT SATURN'S RINGS ARE

Actually, the "rings" are not solid but are made up of a multitude of tiny bodies each revolving in its own orbit around the planet so that they may be regarded as a huge number of tiny satellites. Several rifts, or blank spaces, may be seen in the "rings" where there is an absence of satellites. The diameter of the ring system is about 173,000 miles —about twice the diameter of the globe of Saturn—and they are about 50 miles thick. The innermost "ring" is less dense than the outer rings and for this reason is known as the Crepe Ring.

In addition to the wonderful ring system Saturn has ten satellites, the largest of which—Titan—is equal in size to the planet Mercury. The smallest satellite—Themis—discovered in 1905 has the remarkable distinction of never having been seen directly or through a telescope by the human eye, its discovery and existence having only been determined by the photographic plate.

The globe of Saturn is marked by cloud belts somewhat similar to those of Jupiter, and they also lie in zones parallel to the planet's equator. Similarly,

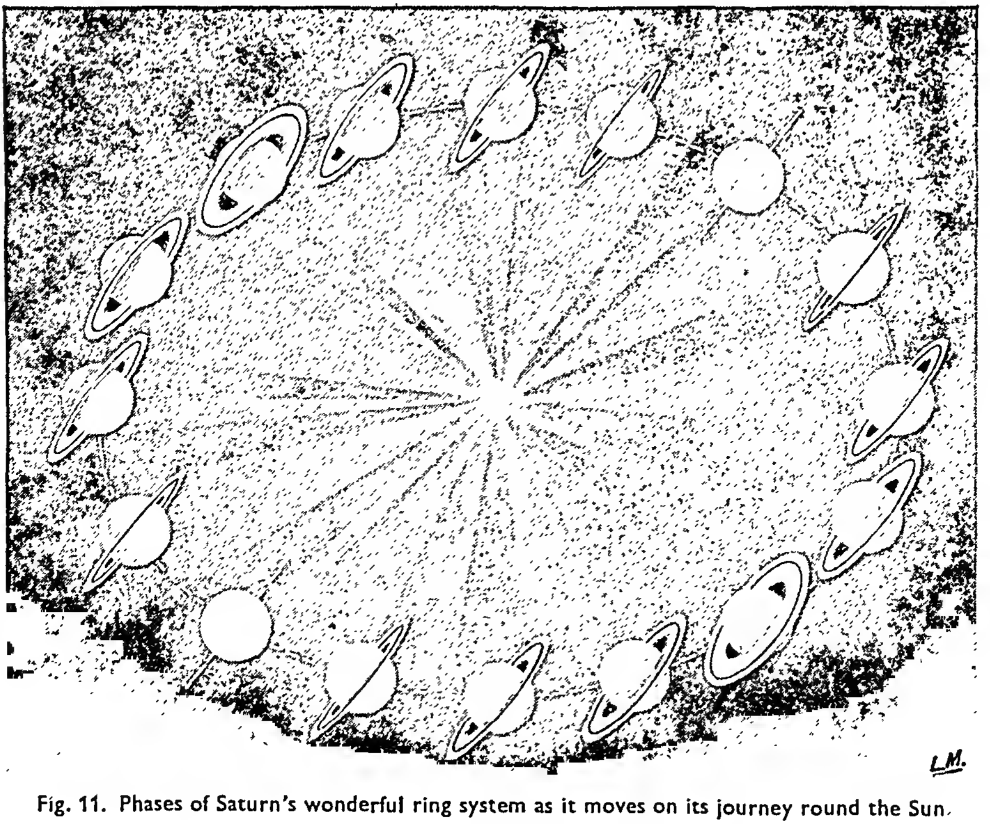


Fig. 11. Phases of Saturn's wonderful ring system as it moves on its journey round the Sun.

the globe is slightly oval, bulging at the equator. This is probably due to the physical condition of the planet and to the fact that it revolves on its axis in the comparatively short period of 10 hr. 15 min.

Of the physical characteristics of the three planets beyond Saturn we do not know much, owing to their comparatively small size and their immense distances. There are interesting stories concerning the discovery of each of them, however, and these we shall briefly detail in the next few pages.

DISCOVERY OF URANUS

Uranus was discovered in 1781 by William Herschel (1738–1822), who deserted from the Hanoverian Guards to become an organist at Bath. He was a born musician and whilst studying the theory of music was led to interest himself in mathematics. From this subject to Optics and Astronomy was but a step, yet it changed the whole current of his life. Astronomy fascinated him and his music became a very secondary consideration—merely a means to an end. All his spare time was spent in constructing telescopes, each one larger and better than the one before. He hurried home from conducting concerts at Bath, and set to work without troubling even to remove his cravat and ruffles. He transformed his house into a laboratory; his drawing-room became a carpenter's shop; and he had lathes even in his bedroom.

As a result of these labours he constructed the largest telescope the world had seen up to that time. He set it up in his back garden and commenced a survey of the heavens, at which task he continued to work for seven years. In 1781 he commenced a systematic examination of all stars over a certain magnitude, and on the 13th March made his great discovery that added a sixth planet to the known solar system.

As seen through any telescope, the stars appear as sparkling points of light of varying magnitude, but the planets appear as discs. Busily examining the stars in accordance with his plan, Herschel passed them in review one by one, noting their differences in magnitude and colour. One of the objects that came into view attracted his special attention, for its appearance was different from that of the objects he had been examining for so many years. It was not a point of light but a tiny disc, and Herschel quickly realised this could be no star. This was confirmed when he noted that, unlike the stars, it had a movement of its own.

Although it seemed that this strange object must be a planet, Herschel did not dare to suggest this, for the five planets—all visible to the naked eye—had been known from ancient times and the solar system long had been regarded as complete. He tentatively suggested that it might be a comet, but subsequent measurements of its movements left no doubt that the object was actually a new planet. The astonishment of the scientific world was unbounded, but it scarcely surpassed the admiration that was aroused for the industry of the Bath musician. Herschel was commanded to appear before George III, who was so impressed by his work that he appointed him his astronomer at Windsor, and in this capacity Herschel continued his observations for many years.

VALUE OF CAREFUL RESEARCH

The discovery of Uranus is an excellent illustration of the value of careful and systematic effort, for it was subsequently found that the object had actually been deliberately and carefully measured on no less than seventeen occasions by different astronomers before the memorable night when it was first

examined by Herschel. Any one of these observers, exercising greater care or having greater experience, might have claimed the honour of discovering a new planet.

Uranus is about 31,000 miles in diameter, and is some 1,782,800,000 miles distant from the Sun. On the scale of our model, with the Sun a 9-ft. globe, it would be represented by a 4-in. globe at a distance of 3½ miles. It has four satellites, two of which were discovered by Herschel.

HOW NEPTUNE WAS FOUND

Astonishing though the discovery of Uranus was, the finding of Neptune—the planet beyond Uranus—was even more amazing, for it was actually discovered on paper before it was seen in the telescope! This marvellous "triumph of mind over matter" came about in this way.

After its discovery, Uranus was carefully observed and its position noted year by year. Tables were produced giving its exact future positions for several years ahead. This is customary with all the planets, the results appearing in the annual known as the *Nautical Almanac*, which is a kind of astronomical *Bradshaw*. As time went on it was found that evidently there was some error in the tables, for it was noted that Uranus was not "running to time" and was not in the positions indicated by the tables. The calculations were checked over and more accurate tables were published, but again unaccountable discrepancies were apparent between the predicted positions and the planet's actual positions. At length it was suggested that the only adequate explanation was that there must be yet another planet circling around the Sun beyond the orbit of Uranus; and that this other planet, by its gravitational powers, sometimes retarded Uranus so as to make it move more slowly and be late, and at other times accelerated its movement so that it was early.

To search among the tens of thousands of stars for such a body was impossible in those days when celestial photography was unknown. More particularly was this so in this case as the immense distance of the suspected planet would make it far more difficult of observation than Uranus, even assuming its size was the same—a fact that was not established. The alternative was to calculate the position of the suspected planet using the observed discrepancies in the movement of Uranus. Although this was a mathematical problem of surpassing difficulty, it was undertaken by M. Leverrier, a French mathematician, and by J. C. Adams, a Cambridge student. In 1841, Adams had interested himself in the subject and had made a note in his diary to "investigate the irregularities of the motions of Uranus, which are as yet unaccounted for, in order to find whether they may be attributed to the action of an undiscovered planet beyond it; and if possible, thence to determine the elements of the orbit approximately, which would lead to its discovery".

The two mathematicians worked independently on the problem, neither knowing that the other was at work. In October 1845 Adams left at Greenwich Observatory the results of his work, showing the hypothetical elements and position of the supposed planet. Instead of making a search, however, the Astronomer Royal paid no attention to the documents handed to him by the young Cambridge graduate, placing them in a drawer from which they were not brought to light until later.

Meantime, in France Leverrier completed his results, and when a copy of these reached the Astronomer Royal, on 23rd June, 1846, he remembered the

papers that Adams had left with him nine months before. Turning them up he was struck by the similarity in the results obtained independently by the two mathematicians. He at once wrote to Professor Challis, who was in charge of the 25-in. telescope at Cambridge, asking him to look in the position indicated for the supposed planet. Before Challis could set to work, however, it was necessary to make a map of the stars in the locality to be examined, and so some time had to elapse before the search could be commenced.

LARGEST KNOWN SATELLITE

Leverrier had also sent his results to Encke, of the Berlin Observatory, where the observers were more fortunate, for it so happened they had recently obtained some star maps, copies of which had not at that time reached Cambridge. The search could be, and was, commenced immediately and a few hours later (on 23rd September) a strange object was found almost at the exact spot indicated by Leverrier. A week later Challis, at Cambridge, found the same object from Adams's figures, and it was soon shown that this was a new planet. Thus one of the mysteries of astronomy was dramatically solved.

Little is known of Neptune: it is situated some 2,793,500,000 miles from the Sun—a distance so great that it is a difficult object to see even with large telescopes. On the scale of our model it would be represented by a 5-in. globe, 5½ miles distant from the 9-ft. globe representing the Sun. Neptune requires nearly 165 years to complete one revolution in its orbit around the Sun. Its only satellite is too small actually to be measured but it has been calculated that it must be over 3,000 miles in diameter to enable it to be seen from such a great distance. This satellite will therefore be the largest in the solar system.

Towards the end of last century, when history repeated itself and perturbations (irregularities) were noticed in the motion of Neptune, there naturally arose the question whether it could be regarded as being the outermost planet in the solar system. The possibility of the mathematicians repeating their achievements with Uranus and Neptune was considered to be practically ruled-out, because in this case the quantities that might be used as a basis were so minute.

Dr. Percival Lowell, whose original work on Mars we have already mentioned, interested himself in the possibility of the existence of a trans-Neptunian planet. He attacked the problem from the point of view of the perturbations that such a planet would have on the movements of Uranus, because Neptune has not even yet been observed over a sufficiently large part of its orbit to enable sufficiently accurate observations to be made. The method he adopted was to account for the various effects of Neptune and the other planets on Uranus, so that should there be any residue unaccounted for, after all known effects were deducted, such residue could only be due to some planet beyond Neptune. Admittedly the amount of this residue would be small—Lowell stated that the value could not exceed 4.5 seconds of arc as compared with the 133 seconds that Adams and Leverrier worked on in 1845.

THE NINTH PLANET

Notwithstanding these great difficulties Dr. Lowell discovered sufficient evidence to warrant a belief that there was a planet beyond Neptune, and that it moved in an orbit with a radius of about 45 times that of the Earth. Early in 1930 a long search—carried out appropriately at the Lowell Observatory—resulted in the discovery of an object in the predicted position (Fig. 12).

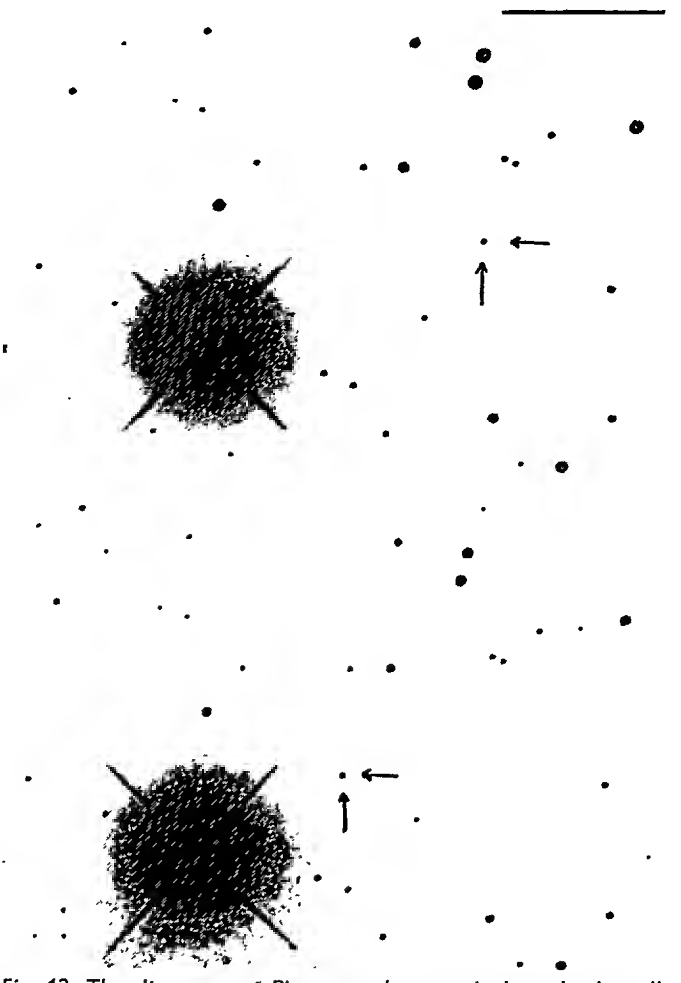


Fig. 12. The discovery of Pluto, as photographed at the Lowell Observatory, on the 2nd and 5th March, 1930. The object indicated by the arrows was seen to have moved a considerable distance and so proved to be a planet and not a star.

Beyond the fact that this ninth planet, named Pluto, is about equal in in size and mass to Mars, we know but little about it as yet. Indeed, some authorities do not regard it as a true planet—it does not yet appear as a major planet in the *Nautical Almanac*—the suggestion being that it may be but an abnormal minor planet. Whatever may be its true designation, its discovery again confirmed the amazing superiority of mind over matter, and all credit is due to the ability of Dr. Lowell and the pertinacity of the observers at Flagstaff who so brilliantly emulated Adams and Leverrier, Encke and Challis.

Having now reached the boundaries of the solar system, we must call a halt, and return for a moment to the space between the orbits of Mars and Jupiter. This space is occupied by the minor planets, or asteroids (Fig. 13), the existence of which was unsuspected until the end of the eighteenth century. Their discovery came about in an extraordinarily interesting manner.

BODE'S LAW

In the year 1772, a German astronomer J. E. Bode (1747-1826) drew attention to a curious relationship between certain figures and the distances of the planets from the Sun. (This relationship was first noticed by Titius of Wittenberg some twenty years earlier.) If numbers be written down of which each (except the first and the second) is double that of the preceding number (thus: 0, 3, 6, 12, 24, 48, 96, 192, 384) and if 4 be added to each number, the following sequence is obtained: 4, 7, 10, 16, 28, 52, 100, 196, 388.

These figures, divided by ten, give fairly accurately the mean distances of the planets from the Sun in astronomical units. (An astronomical unit is the mean distance of the Earth from the Sun,

that is, about 93,000,000 miles). This is clearly shown in the following table:

Planet	*Distance in astronomical units*	*Distance as shown by Bode's Law*
Mercury ..	0·39	·4
Venus ..	0·72	·7
Earth ..	1·00	1·0
Mars ..	1·52	1·6
Asteroids ..	2·77	2·8
Jupiter ..	5·20	5·2
Saturn ..	9·54	10·0
Uranus ..	19·19	19·6
Neptune ..	30·07	38·8
Pluto ..	39·52*	77·2

*This figure is only approximate as yet, and further observations must be made before it can be confirmed.

The above table (shown in relation to Bode's Law), has been compiled in the light of modern discoveries; but when the "Law" first attracted attention only the six planets of the ancients were known. When Uranus was discovered in 1781 it was found that its orbit fitted in with the figure 19·6. With the two outermost planets Neptune and Pluto, the "law" breaks down rather badly, but we are not at the moment concerned with that aspect of the matter.

We are concerned, however, with the fact that in Bode's day—and indeed to-day—there was no major planet which corresponded with the figure 28. It was therefore imagined that there existed an empty zone between the orbits of Mars and Jupiter. Another German astronomer, Kepler, had predicted that some very small planet might be found in this zone, and in 1800, Baron Von Zach and several other astronomers met at Lilienthal and decided to make a systematic search for such a planet. These "celestial police", as they called themselves, divided part of the sky into 24 divisions, one being allotted to each observer, who was to examine the stars in his zone every night in the endeavour to see if there was any strange body among them.

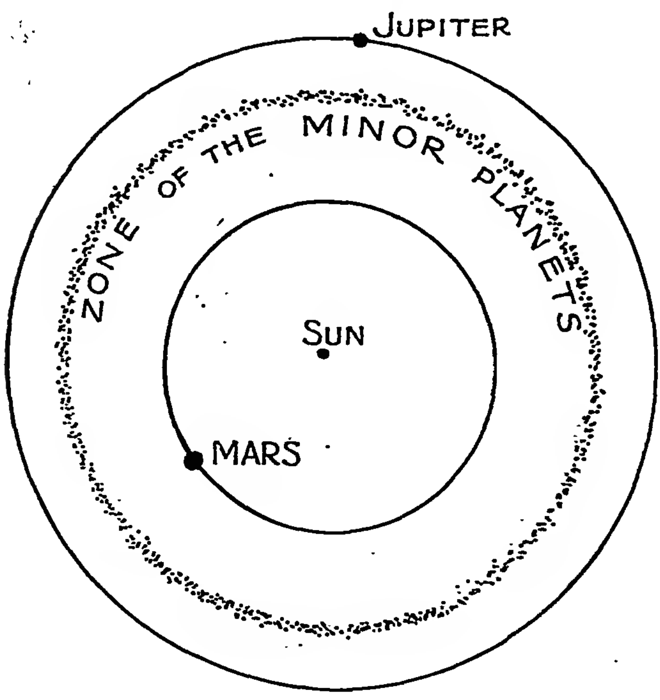


Fig. 13. Where the orbits of the asteroids or minor planets lie.

Before these enthusiasts could get to work, Piazzi, the Director of the Palermo Observatory in Sicily—who was compiling a catalogue of stars—charted the position of what he regarded as a star of the eighth magnitude. Observing this same object on successive nights, he found that it had a motion of its own such as no real star has, and —as Herschel had done with Uranus—he came to the conclusion that he had discovered a comet. He soon realised, however, that what he

had seen was really a new planet, although only a small one. In due course it was found that the orbit of this new planet fell between those of Mars and Jupiter, and as it therefore filled the blank space in Bode's table the solar system was regarded as complete. The new planet, which was named Ceres after the patron goddess of Sicily, is only 447 miles in diameter and is barely visible to the naked eye.

Fig. 14. Three minor planet "trails" during a three-hour exposure. The stars have no trails and appear as stationary dots.

Soon after Piazzi's discovery another small planet was accidentally found when the position of Ceres was being measured. Between 1804 and 1807 two more were added to the list, and since that time more and more of these minor planets have been discovered until now there are over 1,400, on the "permanent list" with over 1,000 "possibles" awaiting further investigations. Every year additional planets are added—in 1936 the new ones discovered amounted to 262—and it is estimated that there are at least 44,000 within range of our present telescopes. It is probable, however, that many of these objects do not deserve the name "planet" being nothing more than large masses of rock circling around the Sun, each in its own particular orbit.

The large number of these planets discovered is accounted for by the fact that most of them have been discovered by photography, by which means their detection is rendered comparatively easy. These planets have a movement of their own, as they circle round the Sun, so that they appear to make a trail on a photograph, whereas the stars appear merely as circular dots (Fig. 14). The most useful of them all is Eros, discovered in 1898 by Witt of Berlin. Although this tiny planet is only 20 miles in diameter its importance exceeds that of all the others, it being used, as we have already mentioned, in measuring the distance of the Sun.

It has been suggested that these minor planets may be the result of some stupendous explosion—that they are the fragments of some large planet that at one time occupied a position between the orbits of Mars and Jupiter. If this is the case it is mathematically certain that there must have been not one but many explosions—first in the original planet and then in separate pieces—for it has been clearly demonstrated that no single explosion could account for the complexity of the orbits of these objects. Another theory—regarded as more likely—is that the material that should have formed a large planet between Mars and Jupiter failed to unite because of the powerful attraction of Jupiter, the force tending to pull to pieces the large planet before it was completely formed.

The path of a meteor (shown by the white streak) across the sky. This striking photograph was obtained accidentally, for the plate was being exposed on the large nebula in Andromeda, seen here as an oval patch in the centre of the picture.

CHAPTER 4

COMETS AND METEORS

EXACTLY why the mention of a comet should arouse such interest among the general public is not clear, for these objects are generally very much overrated from a spectacular point of view. Many comets are discovered every year, but the majority are insignificant and remain telescopic objects only, throughout their career. Seldom is it that there is a comet large enough to give such a brilliant display as was provided by Donati's comet of 1858 or the "Daylight Comet" of 1910.

In bygone times the appearance of a comet was the cause of considerable alarm, the superstitious regarding them as being "ominous of the wrath of heaven, harbingers of wars and famines, of the dethronement of monarchs, and the dissolution of empires". Yet no large comet appeared in 1914, when according to subsequent events, we reasonably might have anticipated the appearance of the largest comet in history! One good thing resulting from these ancient superstitions was that accurate records were made of all comets. These records have been of the greatest service to historians and astronomers in fixing dates and identifying early appearances of those comets that return at regular intervals.

The Chaldeans seem to have regarded a comet as a kind of planet that revolved around the Sun in so large an orbit as to be visible only when moving in that part of the orbit near the Earth. In a sense, perhaps, they were not altogether wrong, at any rate so far as one class of comets is concerned, for it may be that these comets actually are composed of outlying portions of the original nebula from which the solar system was formed, as we shall see later in this section.

Comets belonging to this class are known as solar comets, for they belong to the solar system and revolve in elliptical orbits round the Sun. In most cases these orbits go out into space to distances equal to twenty, or more, times Neptune's distance from the Sun. From this it seems evident that the material from which the solar system was evolved must have extended over this great volume of space. We shall refer to this again in our later section which

Fig. 1. The difference between the paths of solar comets (ellipse) and stellar comets (parabola).

Fig. 2. Morehouse's comet, as seen from Greenwich, 3rd October 1908, showing its multiple tails. The short white lines are stars.

deals with the beginning of the Earth.

The other class comprises the interstellar comets, and—as their name suggests—they travel among the stars and come to us from the depths of space. Their orbits are not elliptical but parabolic (Fig. 1) and the great majority of comets follow orbits of this type. As a parabola is an open curve, the two branches of which stretch away from each other and do not meet, it follows that a comet following such an orbit only visits the solar system once and then returns into space whence it came. Some comets have periods of four years, others of 40,000 years or more. (The "period" of a comet is the time it takes to complete a single revolution in its orbit.)

One of the deciding factors in the type of orbit followed is speed of movement, a comparatively small increase in the speed of a moving body being sufficient entirely to alter the character of its orbit. For example, the Earth moves in its elliptical orbit at a speed of 18½ miles a second. An increase in this speed of only 7½ miles a second would be sufficient to cause the Earth to move in a parabola and to carry it from the Sun.

STRUCTURE OF A COMET

There are two parts to a comet: the head, or nucleus, and the tail. Generally, the heads of all comets are very similar in appearance, although varying in detail as regards size and shape, and perhaps colour. The tails, on the other hand, present wide variations—some are short and stumpy; others are long and curved. They may resemble the shaft of a spear, be curved like a scimitar, or may be twisted and broken. Sometimes there may be more than one tail—Comet Morehouse, which was seen in 1908, had six (Fig. 2)—at others there may be no tail at all. The tail varies night by night, so that the appearance of the tail is no guide as to the identity of the comet (Fig. 3). Being of a tenuous nature, it may have an entirely different appearance at each return towards the Sun.

The tail of a comet is so tenuous that stars may be seen shining through it (Figs. 2 and 3) and for this reason Oliver Wendell Holmes called comets the "spectres of the heavens". A comet's tail always points away from the Sun (Fig. 4), so that the general appearance of a comet is no indication of the direction of its motion. As we cannot rely on the physical appearance of a

comet, the identification of any particular comet depends entirely on recognising the orbit it pursues. At least three observations on different nights are necessary for a preliminary calculation, and a month's observations would give all the information required to compute the orbit with precision.

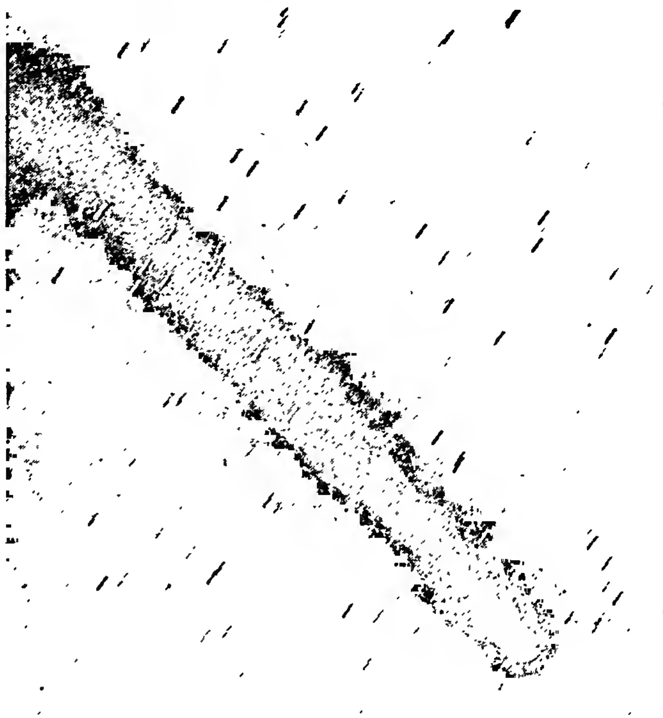


Fig. 3. Morehouse's comet on 29th September 1908. Notice marked difference in comet's appearance in four days, see Fig. 2.

It is estimated that there are probably some 120,000 comets in the solar system, but these are practically all invisible to the naked eye. Only once, in August 1881, were two bright comets visible simultaneously in the same region of the sky. Seldom are more than half-a-dozen visible at any one time but in November 1892 seven were to be seen. In 1932, thirteen comets were seen, but not all at once.

The most famous comet in history is that called after Edmund Halley (1656–1742). Halley, who was born at Shoreditch, assisted Newton in investigating the effects of gravitation on comets and he collected all the observations of comets he could find. Computing the orbits of 24 comets that had been observed in the years between 1337 and 1698, he found that three of them bore such a striking resemblance to each other as to suggest they were not three distinct comets, but three separate appearances of the same comet. The first had been recorded in 1531 by Apian and Fracastor; the second in 1607 by Kepler; and the third in 1682 by Halley himself.

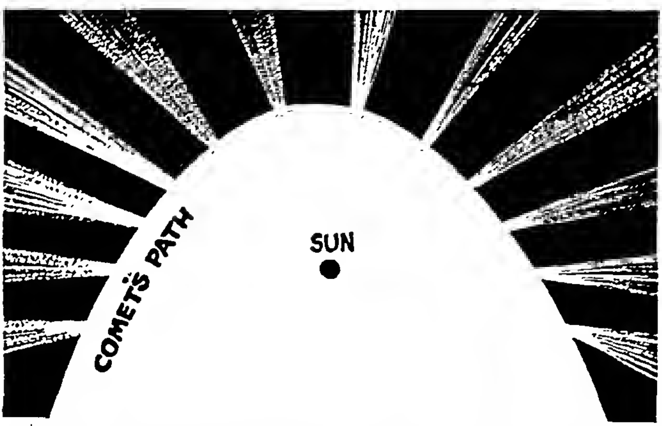


Fig. 4. Twelve successive positions of a comet in its orbit round Sun. Note how its tail always points away from Sun.

Halley noticed that between each date there

was an interval of about 75 years, and on looking up earlier records he found that a similar comet had been recorded in 1456. He came to the conclusion that this particular comet moved in an orbit that required about 75 years to complete. He then took a bold step by announcing that he could "with confidence predict its return in the year 1758. If this prediction is fulfilled", he said, "there is no reason to doubt that the other comets will return". Halley could not hope to live to see his prediction fulfilled but he hoped that "if the comet should return . . . impartial posterity will not refuse to acknowledge that it was first discovered by an Englishman".

HALLEY'S COMET

Although Halley had been dead for some sixteen years when the comet was due to return, his words lived after him. As the year 1758 drew near, mathematicians commenced an investigation, on the assumption that Halley was right, into the perturbations of his comet's orbit due to the attraction of Jupiter and Saturn, the chief disturbing factors because of their comparatively large masses. These investigations required the computation of the distance of the comet from Jupiter and Saturn not only in 1682 but during the previous appearance also. It was necessary to discover exactly what disturbing forces were exercised by each planet over the long period of 150 years. The calculations were intricate in the extreme, and involved labour that occupied three leading mathematicians continuously for six months. Only by great exertions were they able to finalise the matter before the comet re-appeared.

By the end of 1758 they announced that the comet's movement on this occasion would be retarded to the extent of 518 days by the attraction of Jupiter and by 100 days by Saturn, or about 20 months in all. They predicted 13th April, 1759, as the date of the comet's nearest approach to the Sun. As this date drew near astronomers searched the heavens diligently for the return of the wanderer, but it was left to an amateur astronomer named Palitzsch—actually a small farmer, near Dresden—to discover the comet on Christmas night, 1758. The comet reached its nearest point to the Sun on 12th March in the following year, just a month before the predicted date.

No comet could have a more interesting history—in the prediction of its return by an astronomer who knew he could not live to see the fulfilment of his predictions; in the mathematical calculations of the date of the closest approach to the Sun being so nearly correct; in the re-discovery of the object by an amateur, whose brilliant work outshone the professional astronomers'; and, finally, in the complete fulfilment of Halley's prediction. The comet once again, as in the case of Neptune and Pluto, bore witness to the triumph of mind and the might of human thought, able to solve the profoundest mysteries of the heavens.

In 1835 Halley's comet again returned and was found on 5th August by Domouchel, of Rome, close to the place assigned to it. When first observed it was a faint misty object that could be discerned only with difficulty, but later it was visible to the naked eye developing a tail 25° in length, or about fifty times the breadth of the full Moon.

THE COMET'S LAST RETURN

On its last return in 1910 it was rather a disappointing object and did not come up to expectations. For a long time it could not be found, even though photography was now available to assist in the search. As night after night passed

Fig. 5. Discovery Plate of Halley's Comet, which is seen as a dot between two white lines near the centre of the picture.

without any trace of it, the question arose as to whether it had been subjected to some unknown influence in the depths of space so that its orbit had been changed, or alternatively, whether at last it had become "worn out" or disintegrated. On 11th September, 1909, however, all doubts were set at rest when its image was found on a negative exposed by Dr. Max Wolf of Heidelberg (Fig. 5). It was a very faint object indeed but was discovered close to the place where its reappearance had been predicted. Although it was not seen well from the northern hemisphere, in Africa and Australia it was a magnificent object with a broad tail some 90° in length. It looked "like the rays of a powerful searchlight, so long that it reaches from the horizon to the very roof of the heavens" (Fig. 6).

Working backwards through history it has been found that Halley's comet can be identified as having returned regularly at intervals of between 74 and 79 years—the differences being due, of course, to the perturbations caused by Jupiter and other planets—to as far back as the year 11 B.C. On this particular occasion the comet was recorded by Dion Cassius as having been apparently suspended over Rome before the death of Agrippa. In A.D. 66 the comet was recorded by Josephus, who regarded it as a warning foretelling the destruction of Jerusalem. In the year 451 the comet was seen about the time of the Battle of Chalons at which Attila, leader of the Huns, was defeated by the Roman general Actius. The comet's most interesting appearance, however, was that of April 1066, when its remarkable appearance attracted attention all over Europe. The success of William the Conqueror and the death of King Harold subsequently were attributed to its influence by the superstitious. Its appearance on this occasion has been immortalised in the celebrated Bayeux Tapestry, worked by Queen Matilda and depicting events of the time.

The probable composition of comets is connected with the question of "meteorites" or "shooting stars". Nearly everyone has seen at some time or

Fig. 6. Halley's comet as seen from Yerkes Observatory on 4th May, 1910.

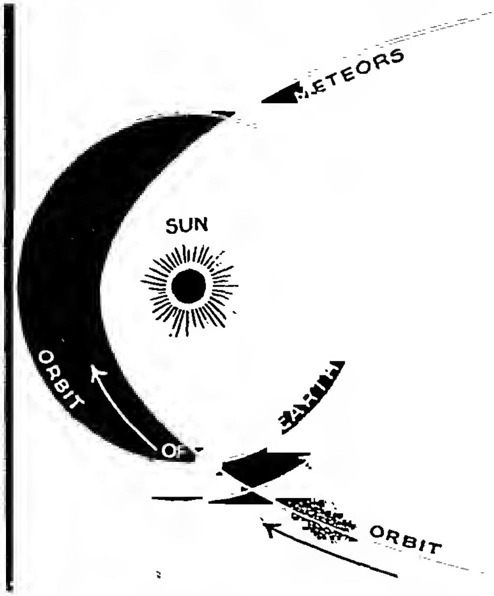


Fig. 7. How the Earth's circular orbit sometimes crosses the elliptical orbit of meteoric bodies.

another what is called a "shooting star" suddenly flash across the sky as a streak of light, to disappear as silently as it came. It seems as though one of the mighty stars of heaven has fallen from its place, but were we to count the stars immediately thereafter we should not find one missing. These objects are not falling stars—they have a more humble origin. The phenomenon actually takes place in the Earth's atmosphere and not in the heavens beyond.

There are multitudes of small bodies circling through space, each in its own orbit and obeying the same laws of gravity as do the planets and other heavenly bodies. Sometimes one of these objects approaches the Earth, or the Earth crosses the orbit in which these bodies are travelling near to the point they have just reached (Fig. 7). When they enter our atmosphere they are heated to incandescence by the intense friction caused by their passage through the air. We see them only when this occurs, as until they enter the atmosphere they are invisible. They have a friction temperature of over 7,000° F., and as they flash through the atmosphere they leave behind them an incandescent cylinder of air 12 to 15 miles long.

SHOOTING STARS

Some of these shooting stars, or meteors, may be seen on almost any clear night and are probably even more numerous in the daytime. Hundreds of millions are captured by the Earth every year, but the majority are too small to be seen. The capture is due of course to the gravitational pull which the

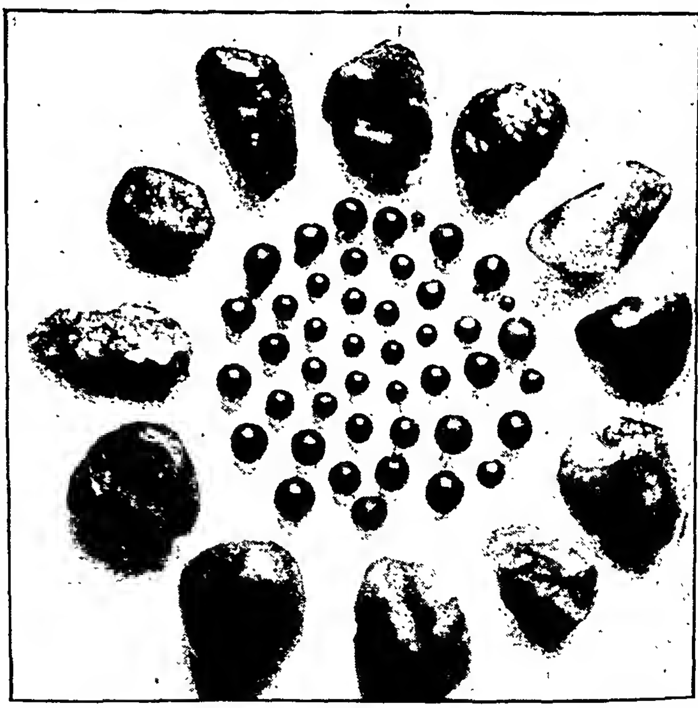


Fig. 9. Meteoric iron dust (small spherical objects in centre) seen through microscope compared with grains of sand (outer ring).

Earth exercises. With a few exceptions they are dissipated before they reach the Earth and form very fine meteoric dust that is visible with a microscope as tiny metallic globules—like microscopic shot—beside which sand grains appear to be blocks of rough stone (Fig. 9).

On certain nights more meteors are visible than on others, owing to the fact that these objects travel round the Sun in streams, and on these nights the Earth crosses or approaches such a stream. These streams result from the gradual drawing out along their orbits of the individual members of a swarm of meteoric bodies. On certain nights the Earth regularly crosses various meteor streams as it pursues its journey round the Sun. The dates each year when this occurs are well known, the most familiar being that of 13th November, on which night in 1833 there was probably the finest shower of meteors ever seen. It was remembered that a similar display had been seen in 1799, thirty-four years before, and records showed that a similar shower had been seen at intervals of thirty-three or thirty-four years for at least 1,000 years.

When the paths of the 1833 meteors were traced in the sky it was found that they seemed to radiate from the constellation called Leo, and for this reason this particular shower is called the Leonids. The return of the Leonids was confidently predicted for 1866 and again an impressive spectacle was seen, but in 1899 they did not come up to expectations—indeed, they failed to appear at all. Something had happened to the stream, but exactly what is a mystery. The most likely explanation seems to be that the orbit of the stream was altered by the attraction of Jupiter. Although some Leonids are seen every year about 13th November, we do not know in what year the Earth will again pass through the main swarm, if ever.

Fig. 10. The internal structure of a meteorite. Etched with acid, the meteorite shows that it is almost all iron. This is a section from a meteorite which struck the Earth in New South Wales.

Although the majority of meteors are dissipated by friction with the atmosphere before they reach the Earth's surface, there have been occasions when some—perhaps larger than the majority—have managed to penetrate through the atmosphere. Such objects are variously termed meteorites, aerolites, bolides, or siderites, and many excellent examples may be seen in the Science Museum, South Kensington and elsewhere (Figs. 10 and 11).

No two meteorites have the same composition and some fifty different

Fig. 11. This $7\frac{3}{4}$ lb. meteorite fell at Rowton, Shropshire. It is composed of meteoric iron.

types are recognised. While some are largely composed of kamacite and others of schreibersite, there are some in which there are no traces of metal. Microscopic diamonds have been found in some, such as in the Winslow Meteorite. Rare gems found in the heart of the Libyan Desert may have had a meteoric origin, and the "Australites" found only in Australia are attributed to a unique shower of glass meteorites.

THE ROWTON SIDERITE

Some 475 meteors actually have been seen to fall to Earth. One of the best known is the "Rowton Siderite" that fell to Earth on 20th April, 1876, at Rowton near Wellington in Shropshire. It was found by a farmer who noticed that after a loud explosion the ground in one of his fields had been disturbed. Hurrying to the spot he found an object buried at a depth of about 18 in. and weighing $7\frac{3}{4}$ lb. It was an irregular angular mass of iron, the edges of which were rounded by fusion during its transit through the atmosphere (Fig. 11).

The majority of meteoric bodies that have at different times reached the Earth have done no harm as they have not fallen on human habitations. On a few occasions there have been more startling occurrences, however, which give us some indication as to what might happen and what damage might be done by the fall to Earth of a very large meteorite, or by a group of these bodies.

An enormous meteorite lies near Grootfontein, in South West Africa. It measures 10 ft. by 10 ft. by 4 ft. and weighs about 70 tons. When it struck the Earth the impact must have been terrific, for it made a hole 5 ft. in depth in the limestone rock on which it fell. Analysis of this meteorite shows that it contains 6 per cent. of nickel and is so tough that two hours' work and a dozen hacksaw blades were required to cut off a small piece.

In 1908 a swarm of enormous meteorites fell near Kansk in Northern Siberia, where an area of several miles looked as though it had been subjected to a bombardment by heavy artillery. Millions of trees were destroyed and craters, like war-time shell-holes, up to 150 ft. in diameter and 12 ft. in depth were formed in the ground. Kansk is a very isolated region and no one saw the actual fall of the meteorites, but the roar was heard 400 miles away. The accompanying air wave was recorded as far away as Cambridge, in England, although at the time its cause and origin were unknown.

It was probably a prehistoric fall that resulted in the formation of the meteor crater in Arizona, U.S.A. Here in a vast stretch of desert country—the hunting ground of the Apache Indians—is an enormous circular depression, the floor of which is 440 ft. below the desert (Top, Fig. 12). Some years ago small pieces of meteoric iron were found in the vicinity and this discovery resulted in the idea that this great crater was the result of the fall to Earth of a gigantic meteor. A close study of

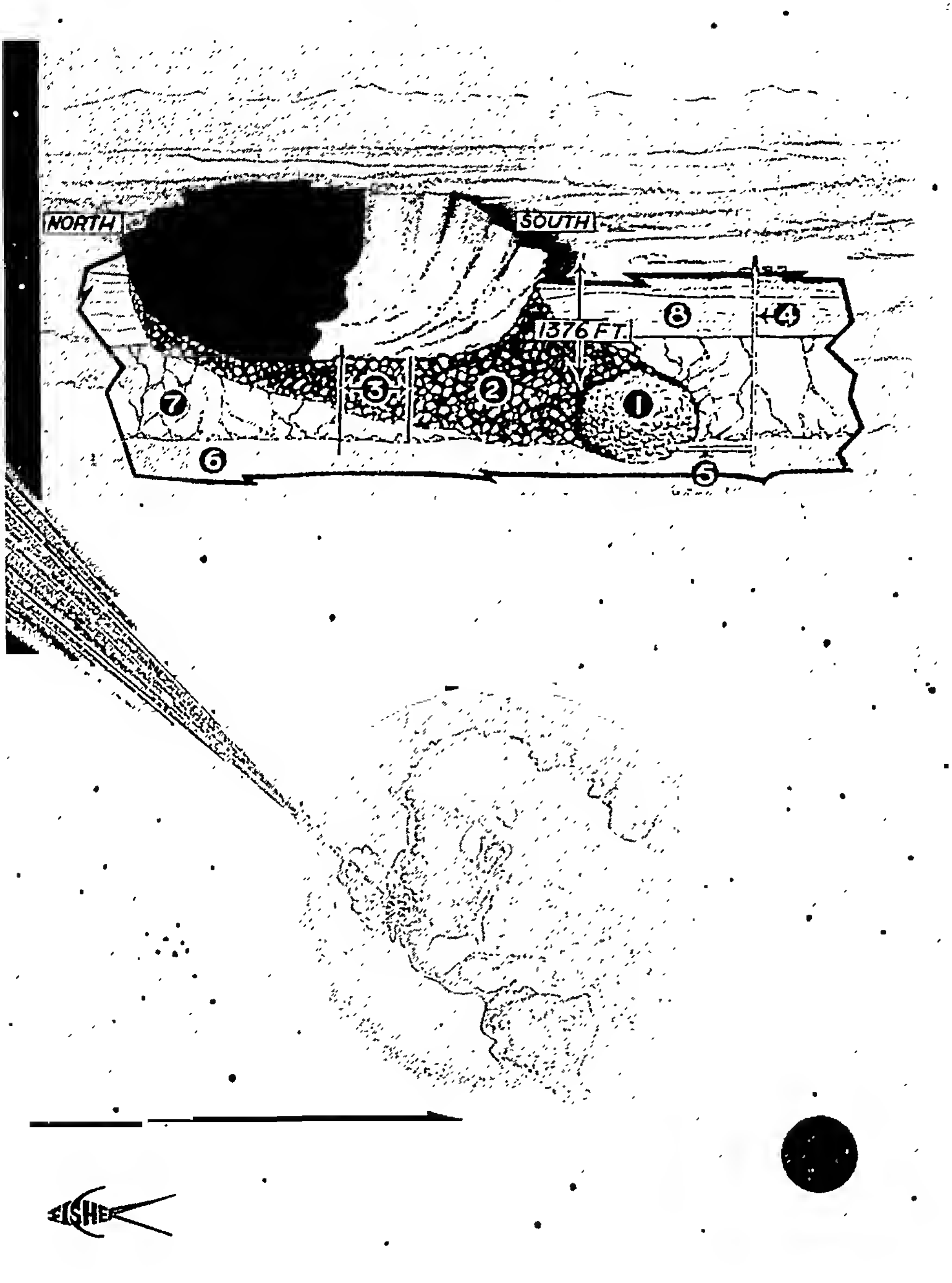


Fig. 12. The Great Meteor Crater of Arizona which may have been caused by a comet hitting the Earth. Top, is a section of crater (see text) and ground around it. (1) Supposed position of meteorite. (2) Shattered rock. (3) Early borings. (4) New shaft. (5) Proposed tunnel. (6) Hard red sandstone. (7) White sandstone. (8) Limestone.

the formation resulted in confirmation of this theory, for it was found that although the upper part of the rocks in the district are laid horizontally there are many large masses that are standing vertically (Fig. 13). Then again, the rocks inside the depression have been shattered and the fragments strewn in all directions. Some of the softer rocks have been ground to powder, and much debris—evidently from the layer of rocks that covered the site of the depression—is scattered about outside the crater, mixed with meteoric iron. So much meteoric iron has been collected around this spot that the quantity exceeds that collected from the whole of the Earth's surface.

It is now believed that the depression is due either to a closely packed swarm of meteors or a comet that collided with the Earth (Fig. 12). No other meteor has penetrated further than 12 ft. into the ground, so that to form such a huge hole in the Earth, the impact and the mass must have been enormous. Basing their calculations on the penetrative effects of shells from heavy artillery, experts have calculated that to have formed such a hole the mass must have weighed at least 10,000,000 tons. Astronomers have therefore suggested that the mass in question may actually have been the head of a comet.

DIGGING FOR METEORIC IRON

The meteoric iron must be buried in the depression, and as the metal must be of considerable value—it probably contains nickel and the rare metals platinum and iridium—attempts have been made to excavate it. So far these attempts have been unsuccessful, despite the sinking of 29 bore holes, because these were sunk vertically, it having been assumed erroneously that the meteorite entered the Earth vertically. The bore holes went down 1,400 ft. to a bed of hard red sandstone evidently not reached by the meteorite because no fragments of this rock were thrown out on the surrounding surface.

A new examination of the matter suggested that the meteorite did not plunge vertically to Earth, but at an angle, and that therefore the mass would be lying not below the centre of the crater but beneath the rim. Further observations of the crater confirmed this idea, for it was noticed that on the southern side the amount of material thrown out was greater than at any other point, and it was also seen that part of the southern rim had been lifted 100 ft. From this it is believed that the meteor approached from the north and buried itself under the southern rim, heaving up the strata above. A trial bore was therefore made from the southern rim and at 1,200 ft. broken sandstone and fragments of meteoric iron were brought up, the proportion of iron increasing until at 1,376 ft. the drill became permanently stuck. Just before further drilling became impossible, three-quarters of the material brought up was oxidised iron of meteoric origin. Such a quantity could not have penetrated to a depth of ¾ of a mile unless it was part of an enormous mass, and there seems little reason to doubt that the abandoned drill is in contact with the meteorite itself (Fig. 12).

As to when this great body collided with the Earth we have no means of knowing. It is interesting to learn, however, that the Indians remaining in the district have a tradition that the great crater-like depression was made by one of their gods who descended from the sky in clouds of fire in order to bury himself there. The crater has certainly been there for over 700 years, for a tree growing on its edge showed by its tree-rings that it had been growing for that length of time. The fact that

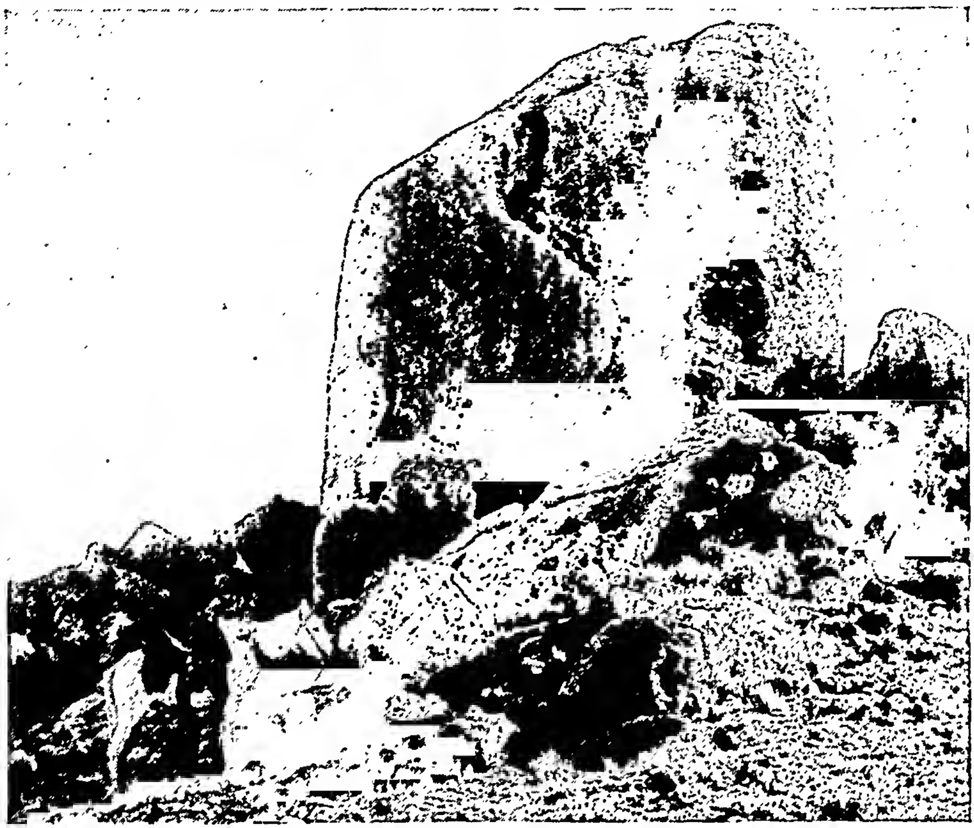


Fig. 13. An originally horizontal rock on the edge of Meteor Crater, forced vertical by the impact.

the broken limestone around the crater does not show traces of great chemical erosion indicates that the impact was not earlier than 5,000 years ago. Probably from 1,000 to 2,000 years is a reasonable estimate, but the great Meteor Crater of Arizona remains one of the mysteries and marvels of science.

The Arizona crater is not unique, for there are other similar, but smaller craters in Carolina; on the island of Oesel in the Baltic; and near the Finke River in Central Australia, this last one being largest after the Arizona crater.

That meteors and comets are closely connected is now generally accepted, a remarkable similarity between their orbits having been noticed many years ago. For example, Temple's comet of 1866, which has a period of 33 years like the Leonids, is connected with them. The Perseids, which are seen in August, have been shown to be connected with the bright comet that appeared in 1862. The orbit of Biela's comet—which split into two in 1846—coincides with that of the Andromedid meteors.

It is now supposed that meteors may be the products of the dissolution of comets, and that they consist of minute particles disintegrated from comets along their orbits, such disintegration being caused by the forces of the Sun and the planets acting on the materials of which the comets are composed. The nucleus of a comet, therefore, probably consists of a swarm of meteors, surrounded by a cloud of gas, debris, and dust, on which the Sun acts, causing a stream of gas to be thrown out which forms the tail.

The Great Nebula of Orion, as photographed through the 24in. reflector at Yerkes Observatory.

CHAPTER 5

THE STARS

When discussing the discovery of Uranus by Herschel we mentioned the difference between a planet and a star as seen in the telescope, pointing out that a planet always presents a definite globe-like disc, whereas a star appears as a twinkling point of light. There is as vast a difference in the physical constitutions of the two bodies as in their appearances, for the planets are mere worlds revolving around the central Sun, and with comets and meteors forming what we call the solar system. On the other hand, the stars are actually suns, and our Sun is a star like them—indeed, it would appear as such could we journey into space even as far as Pluto, the outermost planet. If we continued our travels further the Sun would grow fainter and fainter, until but a tiny speck merged into the cloud of other stars in the system to which it belongs. This system in turn is only one of many other similar star systems, "other universes" they are sometimes called, scattered about the heavens.

Many of these other suns—the stars—are larger and brighter than our Sun, some of them enormously so. They vary in size according to their colour, the red stars being larger than the blue stars. To mention the size of these stars in miles, or to express their weight in tons, makes little impression, as we cannot comprehend figures so gigantic. A better illustration, perhaps, may be given by a progressive consideration based on the size of the Earth. We have already mentioned that the planet Jupiter could contain more than 1,000 planets the size of the Earth. Now, the Sun similarly could contain over 1,000

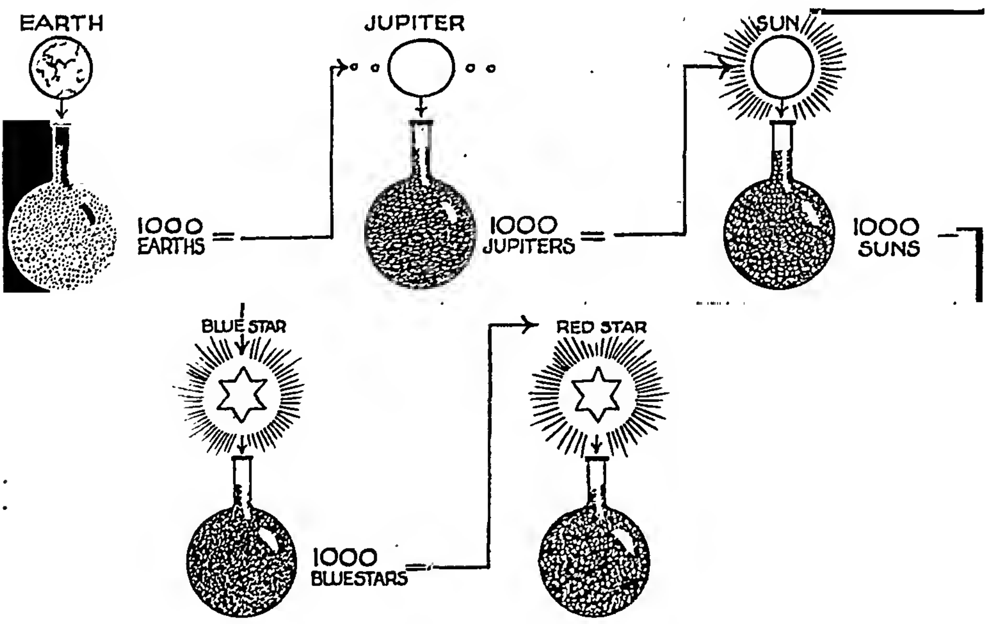


Fig. 1. A diagram illustrating the relative size of the Earth and some of the stars.

planets the size of Jupiter. In the same way, each of the larger blue stars could contain 1,000 globes as large as the Sun, while the largest stars, the red ones, could contain 1,000 blue stars. Fig. 1 demonstrates this diagrammatically.

Fig. 2 illustrates the comparative sizes of three stars in relation to the Sun. Arcturus, *alpha Bootes*, seen at the bottom of the drawing, is the third brightest star to be seen in our northern skies. Arcturus is over one hundred times as bright as the Sun and is 41 light years distant from us. (The term "light year" is explained on page 75.) Betelgeuse, *alpha Orionis*, is a red giant situated about 200 light years distant. It is over 1,200 times as bright as the Sun and over three hundred times its diameter. As the diagram clearly shows, if Betelgeuse were hollow it could easily contain not only the Earth and the Sun, but also the entire orbit of the Earth.

Also shown in comparison is another great red giant, Antares, *alpha Scorpii*. Situated at a distance of over 380 light years, Antares has 4,000 times the candle-power of the Sun, and is over 450 times its diameter. Its mass, of course, is some hundreds of thousands that of the Sun. Electricity, like light, travels at over 186,000 miles a second, so that an electric current will travel seven times around the Earth in a second. So huge

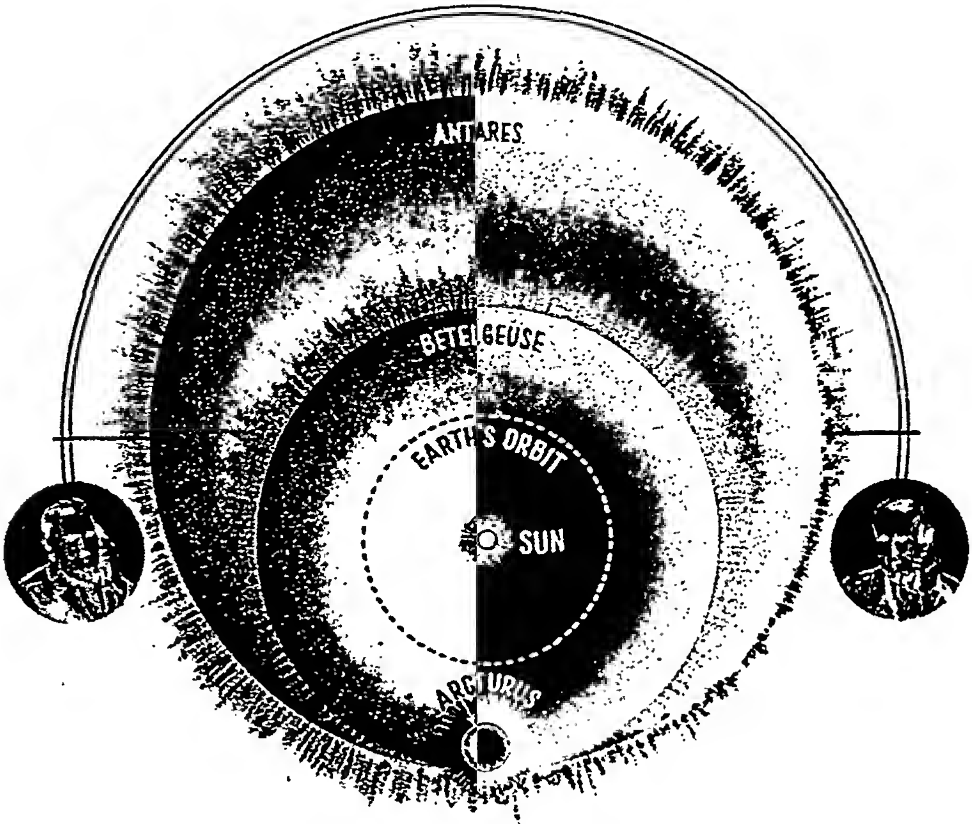


Fig. 2. Antares, Betelgeuse and Arcturus compared with size of Earth's orbit. Antares is so big that an electric current would take 53 minutes to pass half way round the star.

is Antares that it would require 53·3 minutes for an electric current to travel halfway around this star.

Whether any of these suns—the stars—have planets circling around them we cannot tell, for their distances are too great to render visible planets even as large as Jupiter. What we do know, however, is that a large proportion of them have a companion sun—that is to say, they are double stars.

The fact that the Sun is some 700 times more massive than the combined mass of the planets of the solar system is rather a remarkable feature, and appears to be an exception. In many thousands of cases the stars consist of a system of two or more stars of approximately equal size. With every increase in the size of telescopes, more and more stars have been shown to be doubles. In numerous cases, too, where the telescope does not show this, another instrument—the spectroscope, with which we shall deal in a later section—demonstrates the double nature of companions too close to be shown separately by any telescope.

STARS THAT CHANGE COLOUR

Even to the naked eye it is apparent that the stars differ in colour—Arcturus is yellow; Vega, blue; Aldebaran, red, and so on. There seems little doubt, too, that stars change their colours in the course of time. Both Ptolemy and Seneca declared that Sirius was of a reddish hue. Now, 2,000 years later, it is definitely white. Another star in Leo (*gamma Leonis*) was white in Herschel's time but now is golden yellow. A century ago Sestini described the two components of a star in Hercules (95 *Herculis*) as both golden yellow, but shortly afterwards one turned apple green, and the other cherry red. Many of the stars in the multiple systems referred to above display remarkable colour contrasts—whites, yellows and blues. Many pairs have totally different colours—green and red, orange and blue, yellow and purple, and so on.

If we ask anyone how many stars we can see on a clear night with the naked eye we should probably be told "Oh! millions". That is the general impression, yet it is an amazing fact that on a clear night a person with average sight can see only about 1,000 stars! Those who have exceptionally keen sight can see about 1,500 or 2,000 at the most. But there are many more stars than this in the heavens: even a small telescope is capable of showing 120,000.

THE NUMBER OF THE STARS

With our largest telescopes the number that may be seen visually is increased to 80,000,000, whilst those fitted for photography will record many more. The total number of stars that can be photographed by the 100-in. Mount Wilson reflector—at present the world's largest telescope—is 1,500,000,000. It has been estimated, however, that there are probably 30,000,000,000 stars that could be photographed with a super telescope. As in the case of the celestial measurements of size already mentioned, the colossal number of stars, each one a sun, is indeed awe-inspiring and quite beyond our powers of comprehension.

We have already seen how the distance of the Sun is measured. Great though this distance is, it is insignificant when compared with the distances even of the nearest stars. When considering parallax we found that the distance between our eyes is not sufficiently great to enable us to obtain a parallax of a distant object, although quite satisfactory when applied to objects close at hand. In the same way, the base line provided by two observatories at opposite sides of the Earth is too small to show a parallax where the stars are concerned. A much larger base-line is necessary, and this is

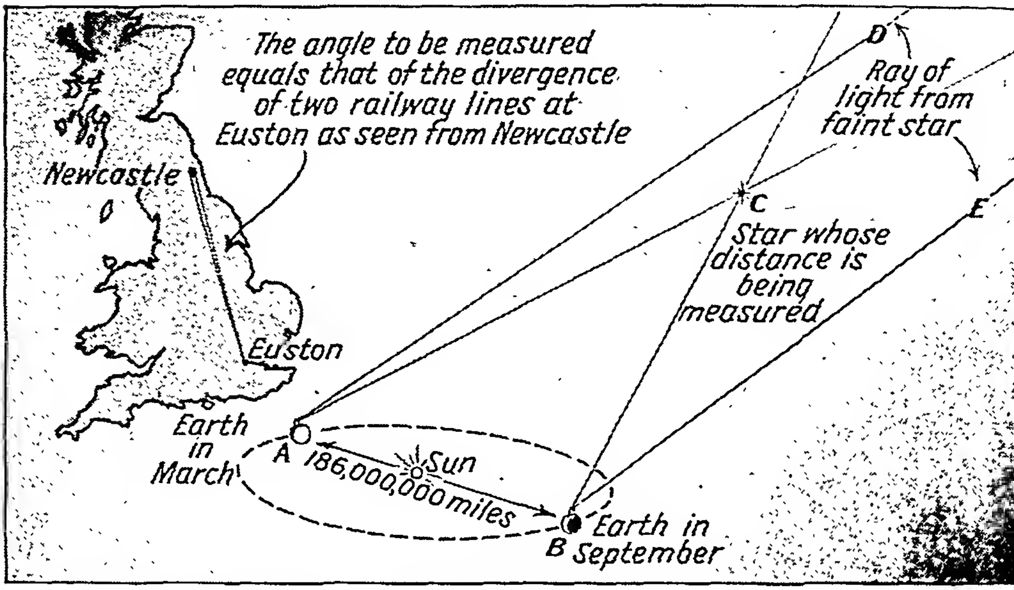


Fig. 3. How parallax enables us to determine the distance of a star. Using the Earth's orbit as a base the apparent shift of position in relation to a more distant star is measured.

provided by the orbit of the Earth. The position of the star to be measured is determined, say, in March and is then measured again in September. In the meantime the Earth has completed half a revolution in its orbit around the Sun, and is at the other end of a gigantic base line of nearly 186,000,000 miles (Fig. 3). If a difference is shown in the star's position in the sky, as compared with that of a more distant star, its distance from the Earth can be found.

Even the gigantic base line thus provided by the Earth's orbit is all too small for the distance of the stars are so enormous that the resulting parallaxes are concerned with extremely minute quantities. We gain some idea of how minute these quantities are from the illustration that if two of the railway lines that start from Newcastle-upon-Tyne met at King's Cross, instead of running parallel over the whole distance, the angle between them would be equivalent to the quantities to be measured in regard to the nearest stars. No star has a parallax as great as 1″ (one second of arc) and that amount is equal to the angle subtended by a man 6 ft. in height at a distance of 250 miles! The nearest star, *Proxima Centauri*, a faint star near one of the brightest stars in the southern sky, has a parallax of ·79 of a second of arc, corresponding to a distance through space of 25 billion miles.

HOW FAR OFF ARE THE STARS?

An interesting illustration may enable us to judge of the immensity of this distance. The fineness of the spider's web is too well known to require elaboration. A quantity of 1 lb. of it would be sufficient to encircle the Earth at the equator. A line could be stretched from the Earth to the Moon with 10 lb., and to the Sun with 3,712 lb. To reach Proxima Centauri would require no less than 500,000 tons!

When measurements of distance are made photographically, on negatives taken of the same region of the sky at an interval of six months, the "shift" of the star under observation is noted in regard to other nearby stars recorded on the photographic plate. A microscope must be employed to determine

these measurements, as the quantities to be measured are rarely more than a few hundred-thousandths of an inch. Fifty or sixty years ago the Astronomer Royal of the day referred to one-tenth of a second of arc as "the smallest thing in the world". To-day, skilful observers using large telescopes are able to measure parallaxes of 16-thousandths of a second of arc. Beyond this extraordinarily fine limit errors of observation may amount to as much as the parallaxes themselves. Despite these fine limits and the innumerable difficulties resulting, over 1,200 parallaxes have been measured with precision.

Expressed in mere miles the distance of Proxima Centauri, the nearest star —some 25,000,000,000,000 miles away— conveys nothing even to the mind of an imaginative person. To express such distances more conveniently, therefore, the speed of light has been used in the following way.

That sound takes an appreciable time to travel over a given distance may be demonstrated without great difficulty. For instance, at a football match when the ball bounces we may not hear the noise it makes contacting the ground until it is several feet in the air on the rebound. Again, if we see a gun fired a short distance away, we first see the puff of smoke but we do not hear the report from the discharge until a few seconds afterwards, the length of the interval depending on our distance from the gun. Similarly, as sound takes time to travel through the atmosphere, so does light take time to travel through space. Sound travels at about 1,100 ft. a second but light is infinitely more swift, travelling at some 186,000 miles a second—the same speed, incidentally, as that of a wireless wave, which travels seven times around the Earth in a second. At this speed light takes about 1¼ seconds to reach us from the Moon, and eight minutes from the Sun. From the nearest star, *Proxima Centauri*, it takes over four years to cross the intervening gulf of space. Thus, were this star actually to cease shining to-day, it would continue to be visible to us for another four years or even more.

THE SPEED OF LIGHT

The speed of light may thus be conveniently used as a kind of "celestial yardstick" to indicate the distance of the stars, and the dimensions of the universe. Measurements by this celestial yardstick are expressed in "light years", for in a year light will travel about 6,000,000,000,000 miles. By this method of reckoning *Proxima* is said to be 4⅓ light years distant. Sirius, the brightest star in the heavens and visible in the south during the winter, is 8 light years distant: Vega, the bright blue star in the constellation of Lyra, is 26 light years distant. Arcturus is 41 light years; and the stars of the Plough, or Great Bear, are 80 light years distant; Betelgeuse, the red star in Orion, is 190 light years away; the stars of the Pleiades, seen above Orion, are 350 light years distant, and Rigel, the blue star in Orion, 540 light years. The cluster of stars in the constellation of Hercules is 36,000 light years away.

Those who care to do so can easily work out the actual distances in miles by multiplying these figures by $186{,}000 \times 60 \times 60 \times 24 \times 365$—and the inclusion or omission of leap years will not greatly affect the resulting mileages!

The brightest stars were given names and the stars were divided into groups, or constellations, in very early times. The constellations resulted from the fancied resemblances of groups of stars to warriors, animals, or other objects on the Earth, just as children imagine that they can see "pictures in the fire". Many stars and constellations are named

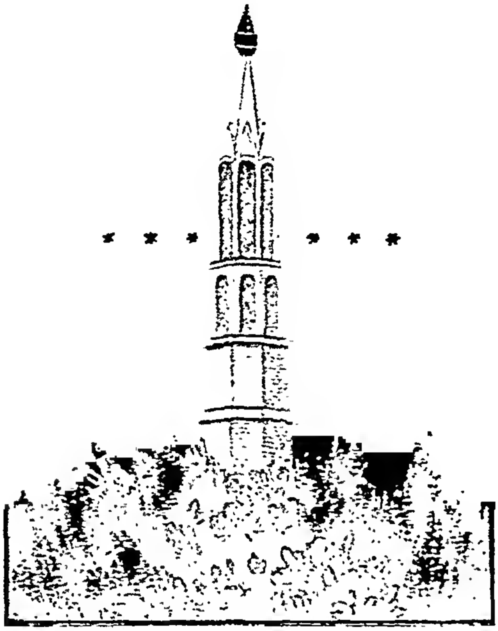


Fig. 4. How a star changes its position in relation to terrestrial objects in the course of a few hours, owing to the rotation of the Earth. You can demonstrate this with an ordinary camera.

after the heroes of the great legends of antiquity. To take classical mythology, for instance, both Perseus and Andromeda are immortalised in the heavens, as also are Cepheus and his wife Cassiopeia—the parents of Andromeda—and the Dragon. In this case, of course, these constellations mentioned represent figures in Greek mythology.

THE EARLIEST ASTRONOMERS

Although it is not definitely known when, or by whom, the constellations were named in the first instance, it is believed that they were mapped out at least as early as 4000 B.C. There is no doubt that the work was originally done by a people who lived near the Valley of the Euphrates, for—just as we know that the Great Bear cannot be seen from Australia, nor can we in the northern hemisphere see the Southern Cross—it is only from this locality that all the constellations named by the ancients can be seen. Probably the people concerned were the Chaldeans, from whom the system of grouping the stars spread to Babylonia, thence making its way through Greek influence to India and the distant East. Although we do not know exactly how many constellations the Chaldeans named, they appear to have named the constellations of the zodiac and probably the forty-eight constellations recorded by Ptolemy.

Because of the rotation of the Earth on its axis, the constellations appear to rise and set, and move across the sky exactly as the Sun and Moon do. We can see the extent of this movement by noticing at any given moment the position of some bright star in relation to some building or church steeple. Checking this an hour or two later it will be seen that the star has moved appreciably (Fig. 4). Naturally the longer the interval between the two observations, the greater the movement. Anyone with a camera can test this out by exposing a film for two or three hours, directing the camera to some bright stars. The resulting negative will show a series of star trails, marking the paths of the stars across the sky. If the camera be directed to the Pole Star, these star trails will appear as arcs of a great circle (Fig. 5), since all the stars appear to revolve around a point near the Pole Star, as we shall explain later.

The sky should not be supposed to be above us as a flat surface, such as the ceiling of a room, but more as an inverted bowl. We shall get a better idea of the heavens if we imagine that the Earth is placed at the centre of a hollow globe, the inner surface of which is studded with stars. Naturally, an observer in the northern hemisphere cannot see the whole of the heavens from any one point in that hemisphere, but only that half

that is above the horizon, the other half being visible to the people in the southern hemisphere.

At the North Pole a bright star is seen directly overhead. This is Polaris, the Pole Star, towards which the axis of the Earth happens to point. From Great Britain we do not see Polaris overhead because we are not "on top of the world", and it appears at some distance lower—or to the north—of the point immediately overhead, which is known as the zenith. As we travel nearer to the equator, Polaris gets lower in the sky until we reach a point from which it is no longer above the horizon.

Because the axis of the Earth points to near the Pole Star, all the constellations appear to revolve around it. Polaris is like the hub of a great wheel and the farther away a star is from the hub the greater is its apparent movement through the sky. For instance, if there were a star 1°—that is twice the breadth of the Full Moon—from the Pole Star, it would have only a small circle of revolution around the Pole Star. A star 20° away would have a much greater circle to complete in the 24 hours.

The stars are in the sky during the day time, but we cannot see them because of the overpowering light of the Sun. As the light begins to fade at sunset the stars "come out", and are seen with the naked eye in increasing numbers as night draws on. Bright stars and planets can be seen in daylight with a large telescope, because by it their light is magnified so much that they are visible in bright sunlight.

WHY STARS RISE AND SET

Owing to the Earth's movement in its orbit around the Sun, we see different constellations at different seasons of the year. The movement of the Earth results in the stars rising, and of course setting, four minutes earlier in each twenty-four hours, this representing the amount by which the Earth moves in its orbit in twenty-four hours. Thus if a star rose on 1st March at 7 p.m. and set at midnight, 60 days later (29 April) it would rise at 3 p.m. and set at 8 p.m.—and for practically all that time would be obscured by the Sun's brightness. Some of the constellations—those nearest the Pole Star—appear in the Northern hemisphere all the year round but others can only be seen in summer; others again can be seen only in winter.

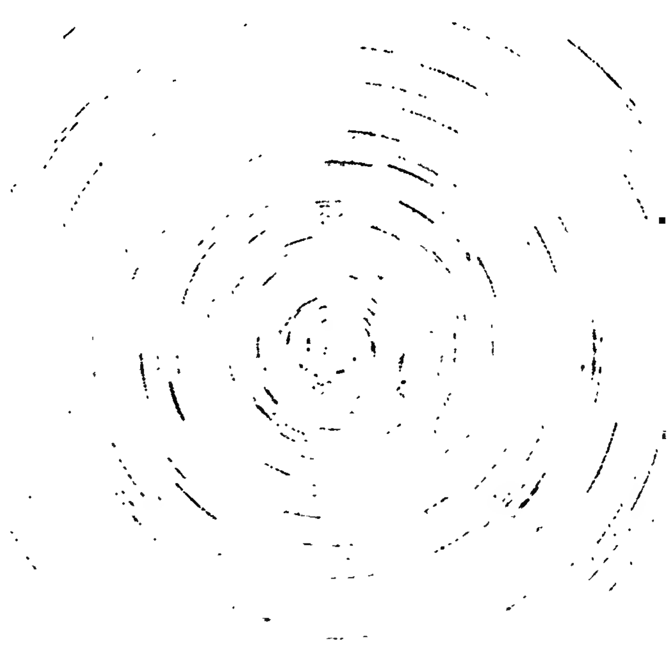


Fig. 5. How stars seem to move round the Pole Star. This time exposure shows how the images of stars appear as trails in great arcs round it. This is caused by the rotation of the Earth.

Fig. 6. The beautiful Bridal Veil Nebula of Cygnus, the constellation of the Swan.

As we shall see in our next section, dealing with the origin of the Earth, it is believed that the solar system originated in a huge nebula—an immense cloud of "fire-mist" that extended in space to a greater distance than the diameter of Neptune's orbit. Similar nebulæ may be seen in the heavens to-day and the number seen has increased with every increase in telescopic power.

In 1781, Messier, a French astronomer, catalogued 103 nebulæ, and later Sir William Herschel recorded some thousands. The use of photography in the study of the heavens resulted in further thousands of new nebulæ being added to the list until, with Professor Keeler's observations at the Lick Observatory, the number grew to 120,000. One illustration will serve to show how photography has assisted in this matter, for when Keeler photographed a nebula in Pegasus he was amazed to find that on the resulting negative not only was the original nebula shown but no less than 20 new ones as well! Later the number of nebulæ was increased to 300,000 by Professor Perrin's researches, also at the Lick Observatory. To-day, the number of nebulæ is estimated in millions, and they are of all sizes and shapes (Figs. 6 and 7). Hubble at Mount Wilson estimates there are 750 spiral nebulæ to each square degree (the diameter of the full Moon is equal to half a degree) of the heavens, giving a total of 30,000,000 in the whole sky.

THE ANDROMEDA NEBULA

Perhaps the most wonderful of all is the nebula in Andromeda (Fig. 7) which may be seen even in a small telescope looking like a tiny oval patch of bright light. Actually, it is comparable in size to our galaxy and is so vast that light requires 50,000 years to cross from one side of it to the other. Its distance is equally beyond our imagination its light taking 900,000 years to reach us. At one time, it was believed that the spiral nebulæ were solar systems in the making, and when Dr. Isaac Roberts, in 1888, obtained his famous photograph of the Andromeda nebula it was widely publicised as showing what our own single star system was like in its early days. However, in 1925 Hubble succeeded in showing that part at any rate of the Andromeda nebula consisted of stars. This led astronomers to conclude that all the spiral nebulæ were not solar systems in the making but actually were other

Fig. 7. The Great Nebula in Andromeda, photographed with a 4 hour exposure, with the 24 in. reflector at Yerkes Observatory. This giant nebula which is really another universe far out in space is so vast that light takes 50,000 years to cross it.

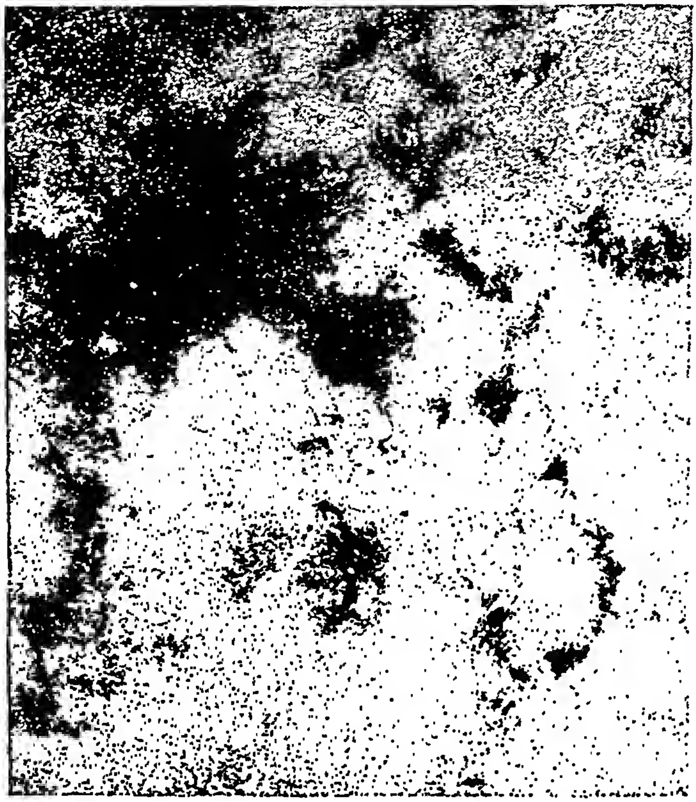


Fig. 8. The Milky Way near the star *Theta "Ophiuchi"* (almost in the centre). Notice the numerous dark lanes.

galaxies—other universes situated far out in space. The modern acceptance of this view means that our visible neighbourhood has been expanded from a radius of 100,000 light years to one having a radius of 100,000,000 light years—a distance utterly beyond the powers of human comprehension.

THE MILKY WAY

The stars appear to crowd together towards that part of the sky known as the Milky Way, but the nebulæ seem to be most numerous where the stars are fewest. To the naked eye the Milky Way appears as a band of misty light stretching across the sky—more distinct in some parts than in others. Photographs show that the Milky Way is actually composed of veritable clouds of stars (Figs. 8 and 9) the distances of which are so great that the eye cannot see them separately, so that only their combined light reaches the Earth. On every photograph—and there are some hundreds—the stars are so numerous that they cannot be counted, and estimates have to be relied upon. These vast numbers of stars are in wonderful formations of irregular clouds and sprays, exhibiting some remarkable features including lanes, holes, and enormous black gaps. These are well seen in Fig. 8, one near the centre looking like the letter S. It would almost seem that these mysterious markings are due to masses of black unilluminated nebulæ which are interposed between us and the star clouds.

At one time it was believed that the Sun was situated near the centre of the Milky Way. Herschel suggested that the stars were arranged in the form of a disc-like grindstone, and that the solar system was near the centre. He pointed out that such an arrangement would account for the numbers of stars increasing towards the Milky Way, for here—according to this theory—we are looking through the length of the disc and consequently the stars appear to us to be more numerous. Later observations have not caused any radical alteration of this theory, and it would seem that our Sun may be one of the stars that form one of the star clouds of our particular universe. It is not now supposed, however, that the Sun is

Fig. 9. Another picture of the Milky Way near *Theta Ophiuchi*, showing the Great Rift.

particularly near the actual centre of the Milky Way; in fact it may be a considerable distance from it—anything from 20 to 50,000,000 light years distant, it is thought.

Although the stars seemed "fixed" in the sky, the constellations remaining identifiable for thousands of years, we know that this is not actually the case. The stars themselves are moving through space—some at tremendous speeds—but so vast is our distance from them that their positions do not appear to the naked eye to alter, even in a century.

THE SUN'S VAST ORBIT

Our own star, the Sun, is no exception to the general rule, for with its attendant planets it is moving through space at a speed of 200 miles a second, travelling around the centre of gravity of its cosmic system. At this speed it requires 250,000,000 years to complete a revolution in its gigantic orbit. How many times the Sun has circled its orbit cannot be determined or even accurately estimated. According to some authorities it must have made thousands, and perhaps hundreds of thousands, of complete revolutions.

As to the possibility of our Sun colliding with some other star as it flies through space, there is little need for apprehension. If a map were made of the solar system, on which the orbit of Pluto, the outermost planet, was 1,500 ft. in diameter, the Earth would be represented by a full stop, thus . On a map of the known universe measuring 15 miles square, the whole solar system would be represented by a similar dot. Thus we see that there is a vast space in which the stars can move with little possibility of any collisions occurring between them.

In the constellation of the Great Bear—actually in the parallelogram formed by the stars of the Plough—is a speck of light beyond the range of the naked eye. By means of our large telescopes this object is shown to be a strongly concentrated cloud of sixty nebulæ at a distance of 150,000,000 light years from the Earth. Even this "super-galaxy"—so named by Professor Harlow Shapley, Director of the Harvard College Observatory—is of small importance when compared with that small part of the universe that we can see from the Earth. In whatever direction we point our telescopes we find other similar "specks"—millions of them scattered throughout space. Can it be, asks Professor Shapley, that all these widely separated objects are themselves obedient members of a single family, reflecting the universality of gravitational law, whilst hinting at incomprehensible intervals of time? Do they oscillate like gigantic pendulums, in periods that run into thousands of millions of centuries? To both these questions Professor Shapley answers: "Yes!"

HUBBLE'S DISCOVERIES

It was in 1934 that Professor Shapley expressed these views before the Royal Astronomical Society, when present in London to receive the Society's Gold Medal. Since then Dr. E. P. Hubble, of Mount Wilson Observatory, has announced that he calculates the boundaries of the metagalaxy—the universe beyond our own—to be not less than 6,000 million light years in diameter, and estimates that it contains 500 million million galaxies!

This is what the 100-in. Hooker telescope has taught us. What further mysteries and marvels will the new Palomar telescope reveal, with its mirror ten times as powerful as the 100-in. and capable of penetrating three times as far into space? It will open up for investigation an unexplored sphere of thirty times the volume of that hitherto

known and, it is estimated, will render visible at least ten times as many stars as are visible at present. It may give us the answer to the supreme mystery of the heavens—do the stars go on, and on—does space go on and on—or does space end, and if so what is beyond the end? Einstein maintains that space and everything in it is curved, and that in the same way that we travel round the Earth and come back to where we started from, so is it with the universe—by which term we include the "other universes" such as the Andromeda nebula. Some astronomers believe that the 200-in. telescope may enable us to determine whether Einstein is right. But in the past we have held similar hopes. Bigger and bigger telescopes have been constructed and have shown—what? Simply, more and more stars. The hope that because we have now constructed a super telescope we shall solve this supreme mystery is one that may not be fulfilled. There are those who see no reason why the extra 100 inches should do more than the extra 60 inches did when the Mount Wilson telescope was constructed and hailed as the "largest yet".

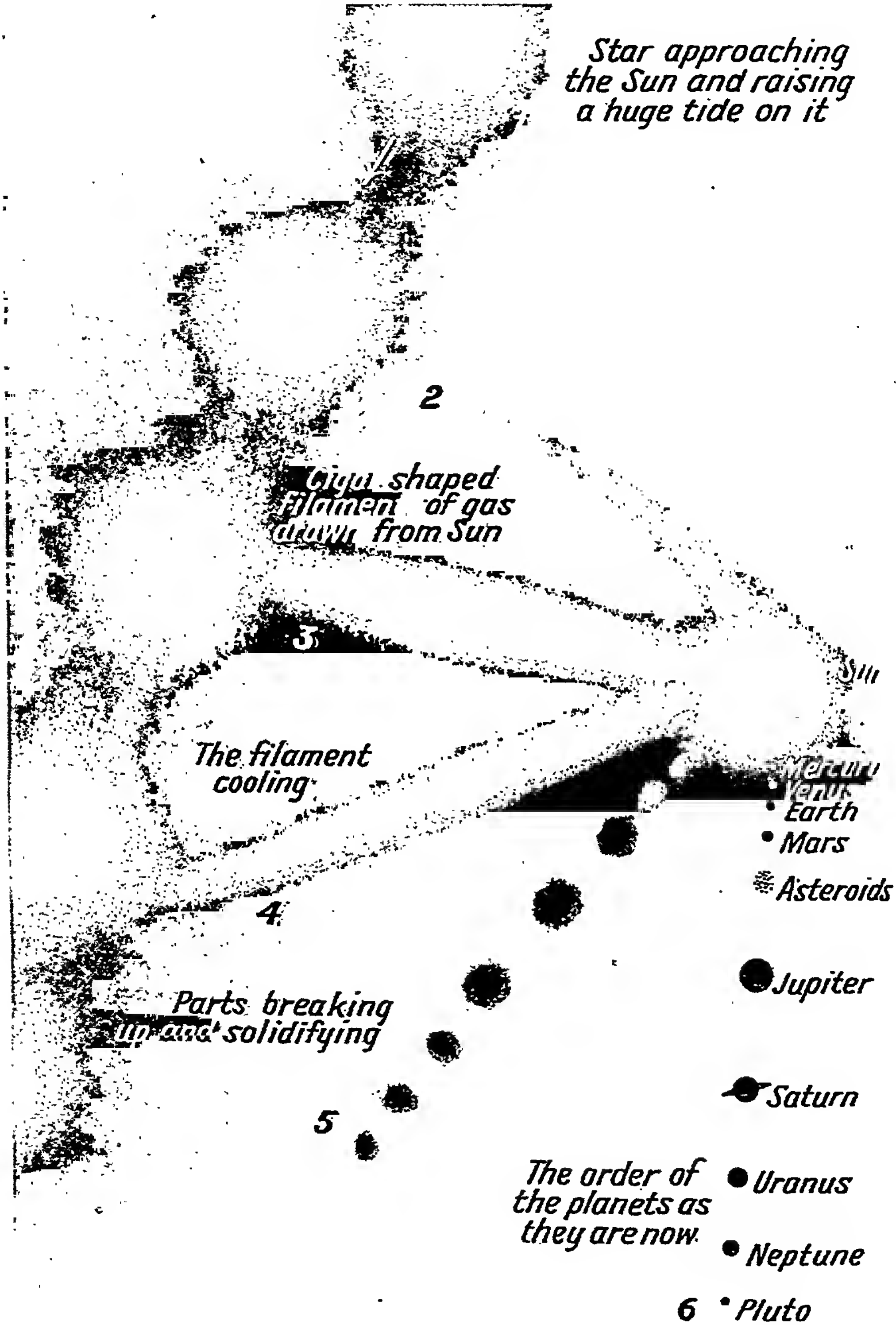
HOW MUCH DO WE KNOW?

Let us conclude this section with a very brief summary of the steps that have led to our present knowledge of the universe. From the conclusions arrived at we shall gain some idea of the enormous strides that have been made by science in the comparatively short period of a century, for it is only about a century since the actual distance of a star was for the first time ascertained (in 1838) by F. W. Bessel. The next step was the discovery that the stars are moving in space like flocks of birds—"flocks" that, as we have explained, have nothing whatever to do with the grouping of the constellations, for these are but man-made starry pictures. In 1904 J. C. Kapteyn, a Dutch astronomer, discovered that there are two main streams of movement, the stars of which are moving in different directions. In 1918, Herschel's suggestion that our Sun belongs to the Milky Way and that this and all the stars we know make up one great star cluster, received confirmation when Professor Shapley showed that the 93 known globular star clusters are a kind of skeleton or framework for the Milky Way. They form a vast system of about 200,000 light years diameter, with its centre some 50,000 light years distant from the Sun.

WORLD WITHOUT END?

Professor Shapley does not think that the universe ends even at the boundaries of this enormous system. In 1923 he found that one at least of the spiral nebulæ is situated beyond—and not in—the Milky Way, and its distance has now been placed at 825,000 light years. In 1920 Hubble, using the 100-in. Mount Wilson reflector, concluded that all the spiral nebulæ—the estimated number of which he placed at 2,000,000—could be nothing less than external galaxies. He suggested that each one is more or less a replica of our Milky Way but situated at a distance so remote that light from some of them requires 146,000,000 years to reach us. In 1932 Professor Baker stated that with our present telescopes we could see external galaxies 250,000,000 light years distant. More recently Hubble has declared his belief that with more powerful telescopes this distance could be increased to 6,000,000,000 light years—but beyond these limits he believes nothing at all exists—not even empty space!

And having carried my readers so far, it will be best to leave them there—alone with their thoughts!



The Birth of the Planetary System. A theory of how planets broke away from the Sun.

SECTION II

OUR HOME, THE EARTH

CHAPTER 6—HOW THE EARTH BEGAN

EVEN in these days when so many of the marvels of science have been explained there are still mysteries, and one of the most puzzling is to answer the question "How did the Earth begin?" There are so few clues to the solution of this problem that the scientific detectives, who have been at work on it for centuries, have only been able to put forward theories.

Nearly 150 years ago the celebrated French philosopher Laplace advanced a theory that was accepted by most scientists during the 19th century. He suggested that the Earth, and indeed the whole solar system, had evolved from a cloud of gas of enormous proportions, such as we see in our telescopes scattered in thousands throughout the heavens. According to his theory this gaseous cloud, or nebula, contracted and condensed and in so doing left behind it, at irregular intervals, huge masses that subsequently formed the planets of the solar system to which the Earth belongs (Fig. 1). The Sun he thought to be the nucleus of this great nebula, and suggested that it was still contracting steadily year by year.

Subsequent research tended to show that Laplace's "nebular hypothesis" could not be the final solution of the mystery, many serious objections to it being advanced in the light of later discoveries. The idea cannot be dismissed entirely, however, for Laplace's theory still receives considerable support because of certain significant facts. These are: that the planets all rotate on their axes in the same direction, a

Fig. 1. A solar system in the making? The spiral nebula in *Ursa Major* the Great Bear. Notice condensations forming stars.

direction that is the same as that in which the Sun itself rotates; and that they all revolve around the Sun in a similar direction. Further, all their satellites revolve also in the same direction—with one or two exceptions that are really of minor importance, for their divergence from the general rule can be accounted for satisfactorily.

LAPLACE'S THEORY

The inference is that the whole solar system was formed from the same swirling nebula, and that when the Earth, for instance, finally broke away from the parent mass, it was released rather after the manner in which a spinning top is released from a whip. The other planets were set spinning in the same way, and the process was repeated on a smaller scale with the planets' satellites, these having been formed from the masses of nebula constituting the separate planets. Both the planets and their satellites continue to spin because they are not retarded by any friction in their movements through space.

Some further confirmation of Laplace's theory is afforded when we consider the important question of how the Sun manages to retain its heat. Helmholtz suggested that this could be accounted for by assuming that the Sun is gradually contracting. He based his theory on firmly established laws governing the contraction of gases. It has been shown that the Sun must at one time have been of infinitely greater size than it is to-day, and must have extended to regions outside the confines of the solar system—which is virtually what Laplace put forward in his hypothesis.

There are several facts that cannot be explained by, or reconciled with, Laplace's hypothesis, although many attempts have been made to fit the pieces of the jig-saw into their places. The final argument against the theory has been advanced by the mathematicians, who are convinced that on the mathematical side alone the difficulties are insuperable.

Chief of these difficulties is the fact that if contraction were to occur as suggested by Laplace it must occur on a far greater scale than he imagined. In other words, the result of contraction would be not a series of planets but stars. We are still left wondering how and why the planets originated.

Without probing too deeply into complex scientific reasons, it can be said that, while Laplace's theory is adequate to account for the birth of a star—such as our own Sun—and indeed is generally accepted as sufficient explanation of how stellar groups or island universes (as they are called) arose, it is inadequate as an explanation of how a planetary system might arise. In other words it does not explain why such comparatively small bodies as planets and their satellites ever appeared in the universe.

TIDAL ORIGIN THEORY

In recent years a remarkable theory has found increasing support amongst scientists. It is now supposed that the solar system as we know it is the result of a very rare astronomical accident. So vast is inter-stellar space, however, that there may be myriads of suns in the universe each possessing its own satellites. But it may equally be true that our Sun is the only star in the heavens that has given birth (in a literal sense) to a number of planets.

The theory supposes that, in some incredibly remote epoch of time, an epoch when our familiar Sun was a far larger and far more magnificent star in the firmament, another star approached it. Inevitably the enormous gravitational force exercised by this star raised vast tides on the Sun. As the star

swept round the Sun and onwards in its course, these tides rose higher and higher until finally a long cigar-shaped filament was torn out from the Sun's surface (see illustration on page 84).

This filament, thin at the tip and broad in the centre, was whirled round through space, following the motion of the Sun. After countless ages, areas of condensation, or contraction, appeared. Gradually these thickened into rough spheres and so the planets were bōrn.

At first they moved round the Sun in rather flat ellipses—only much later did they approach the nearly circular paths they follow to-day. At certain points in their course when they approached nearest to the Sun, they were in their turn subjected to immensely powerful gravitational forces. In consequence, tides were raised on them (for at that time they were still in a molten or plastic state) and masses of material were finally torn off. Thus were born the satellites that revolve round the planets.

Although there are certain unresolved difficulties in this theory, its mathematical requirements are very largely supported by direct evidence. To mention only one example, we may point out that the largest planets, Jupiter and Saturn, do occur where one would expect from this theory, in the middle of the planetary orbits. This theory also accounts for the fact that all the planets in the solar system revolve round the Sun in the same direction.

BIRTH OF THE EARTH

We need not discuss rival theories here: we can content ourselves with the broad statement that the Earth originated as a mass of extremely hot gas. It passed successively through a liquid and a viscous state, shrinking meanwhile until it finally became as it is to-day—a sphere of more or less solid matter surrounded by a crust. As the core contracted, this outer covering wrinkled up to form our great mountain ranges—such as the Himalayas, the Rockies, and the Andes. Originally these mountains may have been a dozen times their present height, but have been denuded and flattened by natural forces such as rain and frost. And there, for the present, we must let the matter rest, leaving further elucidation of the mystery to future scientists.

THE EARTH'S AGE

On the question of the age of the Earth there has probably been as much discussion as on the question of the Earth's origin. In the seventeenth century it was suggested by Archbishop Usher, who was the first to attempt to formulate a Biblical chronology, that the creation of the world took place in 4004 B.C. Such a date is impossible, as is at once evident from the fact that at the date mentioned civilization had existed in Egypt for many centuries. If six noughts were added to the seventeenth-century figure it would then be more in keeping with modern estimates—for any such figures can only be estimates in the absence of direct proof.

To help in solving the mystery of the age of the Earth we rely on the teachings of astronomy, geology, and physics. Let us see what each of these sciences can tell us.

The problem was first attacked by an attempt to determine the age of the Sun. As we have already seen, Helmholtz suggested that the Sun's heat is maintained solely by its contraction. Lord Kelvin (in 1862) came to the conclusion that on this basis the Sun must have existed for 30,000,000 years, and that the age of the Earth could be taken to be approximately the same.

Geologists were not satisfied with this estimate, however, the period being too short in their opinion to allow of

the formation of some of the rocks in the Earth's crust. From measurements of these rocks Phillips estimated that originally the deposits must have been at least 300,000 ft. thick. By comparing the rate at which similar rocks are being formed to-day—a thickness of a foot in a century—he came to the conclusion that the Earth's age must be at least 40,000,000 years. Another geologist, Sir Archibald Geikie, using a similar basis, revised the estimate (in 1899) to 100,000,000 years. Poulton (1896), working from the biological angle, suggested 500,000,000 years as the time necessary for the development of animal and vegetable life to their present stages of evolution.

The problem was attacked from yet another angle in 1909 by Sollas. He took as his basis the saltness of sea water, the degree of which is constantly increasing, as every year more salt is carried into the sea by rivers. He estimated that 150,000,000 years would be required for sea water to have reached its present degree of salinity.

WHAT RADIUM TELLS US

The most recent estimates have been made by the physicists, who were greatly helped in this direction by the study of radio-activity—a line of research that was, of course, unknown to Lord Kelvin whose estimates have been upset by these later discoveries.

Investigation has shown that radium is disintegrating, and that it gradually changes into another substance. In a period of about 1,600 years a portion of radium will have changed so that only half the original portion will be radium, the remainder being a debris that does not possess the properties of radium. By careful measurement, therefore, it becomes possible to determine the age of a mixture of radium and its debris.

Other radio-active substances behave similarly, but the time required for each to deteriorate into half-values varies. One such substance, uranium, changes into debris that ultimately becomes a special kind of lead. The change from uranium into lead takes place at an absolutely uniform rate. By this is meant that no extremes of heat or of pressure affect in the slightest the rate of change and this rate has been very accurately measured in the laboratory. Physicists are able to say—from the fact that in no case is the uranium as found in various rocks less than its accompanying debris—that uranium cannot have been in those rocks for as long a period as 4,500,000,000 years. Careful measurements of the amount of uranium and the amount of debris suggests that the uranium has been present in the rocks for some 1,500,000,000 years. A similar period is arrived at from the examination of thorium, another radio-active substance.

It has been discovered that at Morogoro, in East Africa, there is a deposit of pitch-blende—a black oxide of uranium used in colouring glass pale sea-green. This deposit contains a proportion of lead of the special type that is the final product of the radio-active changes undergone by uranium. Experiment has shown that the time required to produce the proportion of lead present in these Morogoro deposits is 700,000,000 years, assuming that the parent uranium was originally pure. Of other minerals examined in this way the "youngest" proves to be 320,000,000 and the "oldest" about 1,230,000,000 years old.

If we assume that the crust of the Earth solidified some 1,500,000,000 years ago, we must add considerably to this figure to allow for the cooling of the Earth and the formation of the crust. Some guide as to what the final figure is likely to be may be obtained from Professor Rutherford's researches into

the relative abundance of uranium and allied substances, for he found that the greatest possible age for the Earth is 3,400,000,000 years. It is safe to say that the Earth is between 1,500,000,000 and 3,400,000,000 years old.

Taking as a provisional figure 2,000,000,000 years, let us endeavour to see what it represents. It is more than 100,000 times the length of human history, and more than 1,000,000 times the length of the Christian Era. In this book there are about 175,000 words. If we take as an average six letters to a word, we have a total of say 1,000,000 letters. The length of human history would be represented by the last word in the book, and the period since the birth of Christ by less than the last letter! The whole of the remainder of the book, with the exception of the last word, therefore, represents the time that passed before Man appeared on the Earth. It is an interesting thought to remember that the Earth existed for thousands of millions of years before Man came; that it will probably exist for thousands of millions of years after Man has vanished; and that the whole of the period of life on the Earth is but a brief span between these two periods of the Earth's existence.

FIXING A DATUM LINE

To many, however, the fact that estimates of the age of the Earth have been increased by two hundred times in sixty years, will suggest that the last word has by no means been said, and that we must wait for further evidence before we accept even the most recent estimate. And we may profitably pause to ask ourselves if we should not consider more closely exactly what we mean by these millions of years we speak about so glibly. It is desirable that we should fix some kind of a "datum line" in regard to what we call Time. On the one hand we have the "dance of the electrons" in which these inconceivably minute particles rotate around their parent atomic nucleus a million billion times in one of our seconds. On the other hand, perusing the tables compiled by Professor Eddington of the astronomical periods required for the life of a star, we find that the duration of one stage alone requires twenty billion years! Somewhere between the two extremes is the mystery of the age of the Earth.

THE EARTH IS NOT FLAT

That "appearances are deceptive" everyone will agree, and we may excuse those who suppose, from the appearance of a rolling landscape or a wide desert, that our Earth is flat. But we cannot excuse those who persist in this belief despite irrefutable proof showing that the Earth actually is a sphere. That there are such people is shown by the fact that there exists a "Flat Earth" society the members of which are convinced that everyone in the world must be "out-of-step" but themselves.

Several things show that the Earth's surface is not flat. There is the well-known fact that a ship gradually disappears over the horizon, whether it steams north, south, east, or west; and that as its distance increases, first the hull, then the deck, funnels and masts, sink below the horizon (Fig. 2). Even a small telescope will show the topmasts when the ship is "hull down". If the Earth were flat the whole ship would fade away gradually as the distance increased. Sometimes this illustration is incorrectly advanced to prove that the Earth is a globe. It does not prove this, of course, but only that the Earth's surface is curved. Conversely, when approaching land, the look-out in the "crow's-nest" first sees the highest peaks of a mountain range, and as the ship draws nearer to the

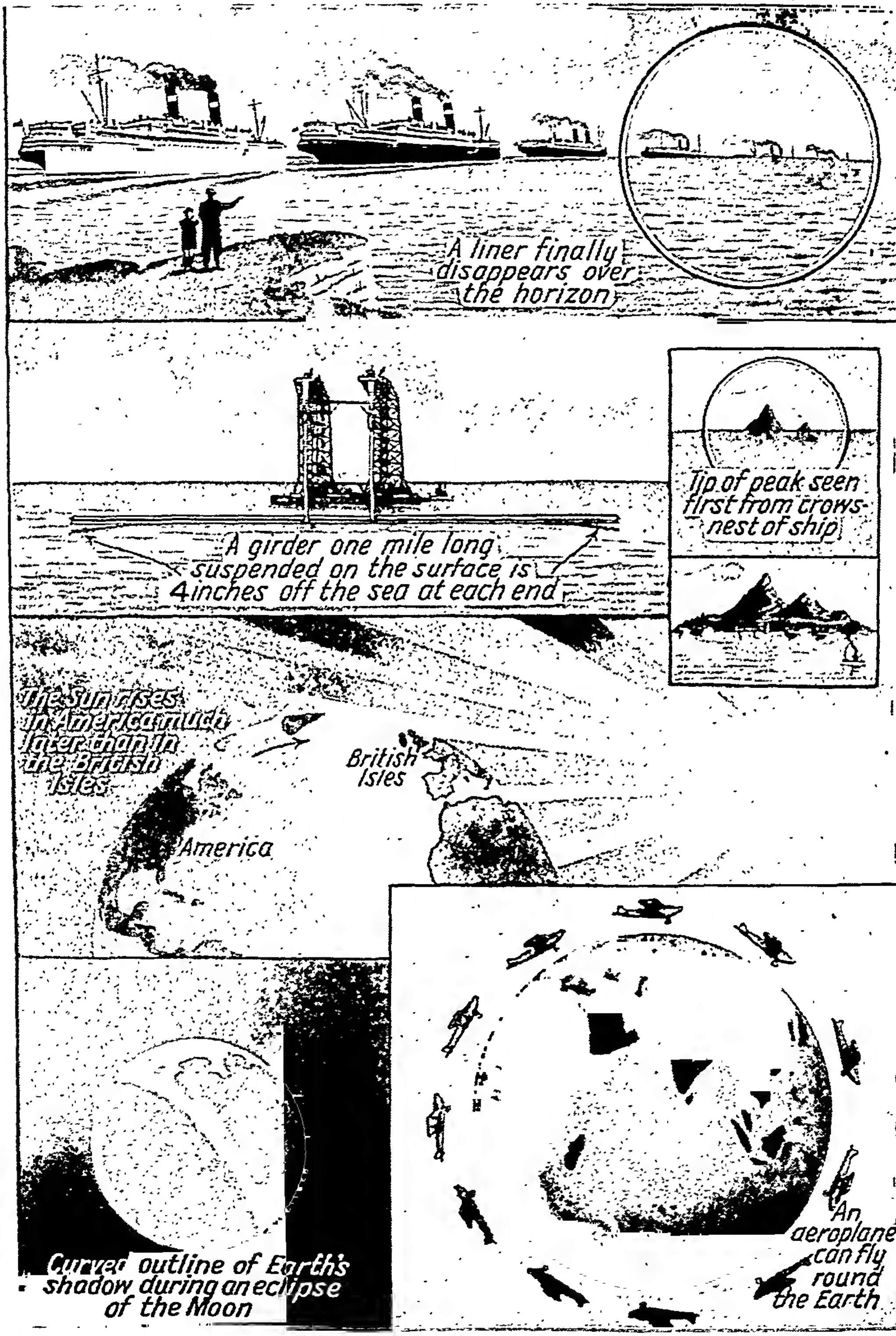


Fig. 2. Various methods of proving conclusively that the Earth is not flat.

land, more and more of the mountains become visible (Fig. 2).

An astronomical proof that the Earth cannot be a flat plain is afforded by the fact that the Sun does not rise at the same instant in every country. It does not rise to inhabitants of America until some six hours after it has risen in Britain, and at the same time it is setting in India and Central Asia (Fig. 2).

THE EARTH A SPHERE

The most modern proof of the curvature of the Earth's surface has been provided through recent advances in photography. By means of films made sensitive to infra-red rays, which are able to penetrate haze and fog so that distant objects can be "seen" by the camera, photographs have been taken from an aeroplane of a far-distant horizon from such a height that the curvature of the Earth is distinctly apparent (Fig. 3).

Actually the amount of curvature is comparatively small, being only 8 in. to the mile. That is to say, could we obtain a level girder a mile in length and suspend it over the sea on a calm day with the middle just touching the surface of the water, each end of the girder would be 4 in. above the water (Fig. 2).

Proof that the Earth is a sphere can be given in several ways, as for instance by the fact that if we travel continually in the same direction we return eventually to our starting point. Astronomically there are several proofs, as for example in an eclipse of the Moon which anyone may see perhaps once or twice a year. When this occurs the Moon passes through the great shadow cast by the Earth in space, and as we watch the Earth's shadow creeping over the surface of the Moon, we see that the edge is circular in outline (*see* Fig. 2, page 90). Only a globe will throw a shadow that is circular under all conditions. The ancients knew that a lunar eclipse is caused by the Moon passing through the Earth's shadow and Manilius and Cleomedes, two astronomers who lived some 2,000 years ago, advanced this as a proof that the Earth is spherical.

Although the Earth is a sphere, it is not a perfect sphere for it is slightly flattened at the poles—or to put it in another way, it bulges slightly at the equator. To say that the Earth is flattened like an orange is not altogether correct, for the equatorial diameter is only 26 miles greater than the polar diameter (Fig. 4). As this represents a difference of only about 1 part in 304, a similar amount of flattening in an orange would not be noticeable to the casual observer.

The reason for this bulging at the Earth's equator is that it is rotating on its axis at a comparatively high speed. Every particle of matter of which the Earth is composed is subjected to centrifugal force—the tendency of bodies to be forced perpendicularly away from the axis of rotation. In the case of the Earth this force is not really very considerable and consequently the equatorial bulge is negligible. As we have already seen, however, some of the other planets are rotating at a much greater speed, and in their case the equatorial bulge is obvious at a glance, particularly in the case of Jupiter.

EFFECT OF GRAVITY

So long as the effect of gravity is sufficient to counteract centrifugal force, there is no likelihood of our being thrown off the Earth into space. As the Earth's rotation carries objects at the equator through a distance of 24,902 miles in 24 hours, we can see that their speed is approximately 1,000 miles an hour. If the Earth were to be "speeded up" suddenly to seventeen times its

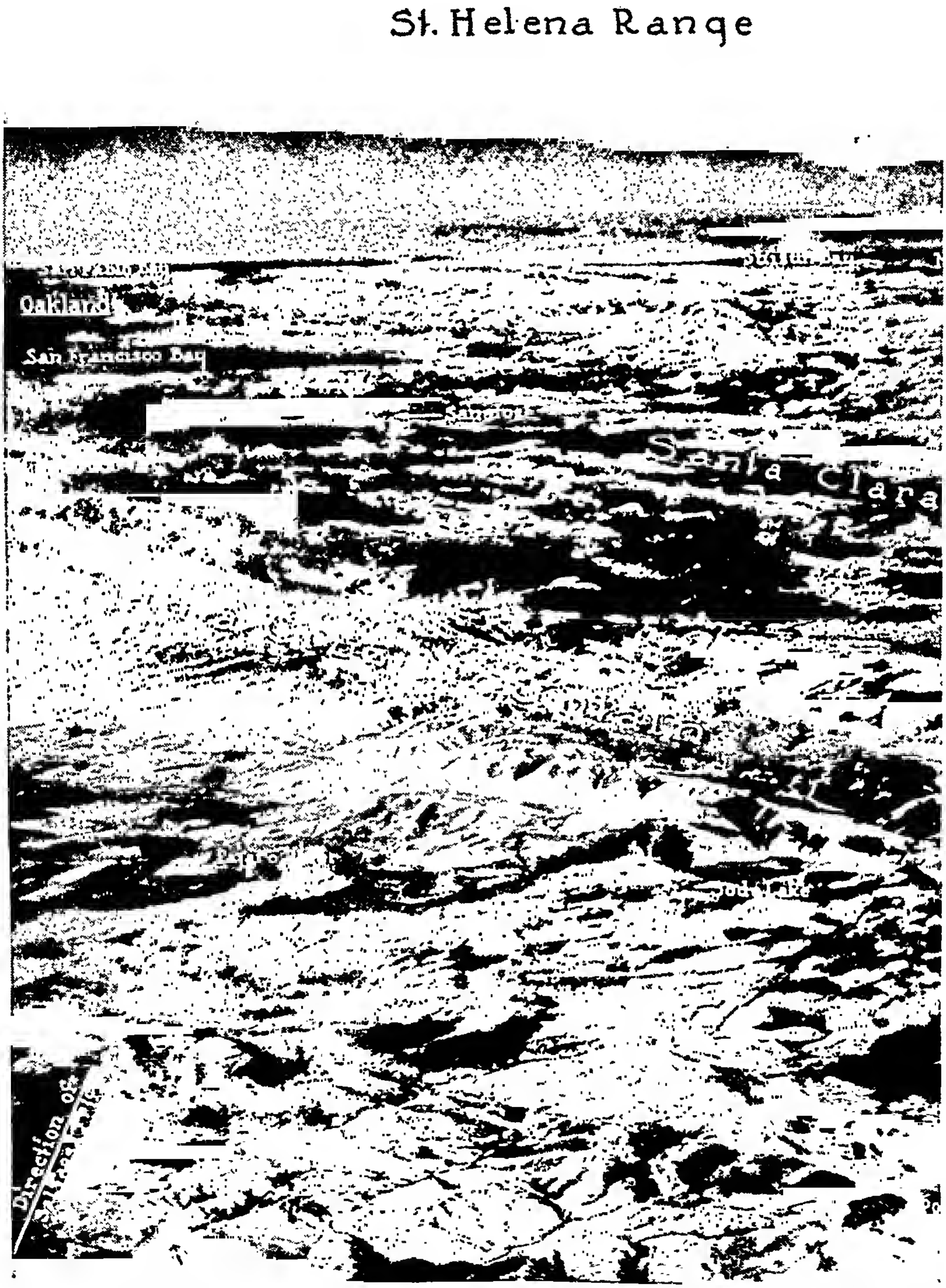


Fig. 3. This astonishing infra-red photograpn, taken from a height of 4¼ miles, covers an area of Western America with a radius of over 331 miles. In the original negative the curvature

of the Earth is distinctly seen on the horizon: it may even be detected in this reproduction. Infra-red photography has made such pictures possible, since it can penetrate haze and mist.

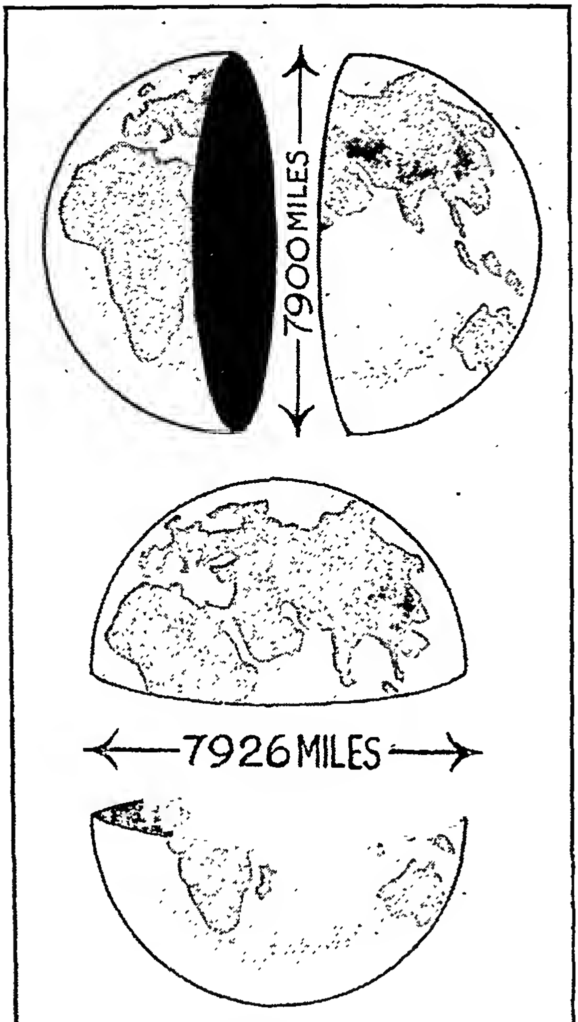


Fig. 4. The difference between the Polar diameter (top) and the Equatorial diameter (bottom) of the Earth.

present speed, so that it completed a rotation in 85 minutes, everything at the equator would rise into the air and disappear into space! Fortunately, the pull of the Earth's gravity is more than sufficient to counterbalance centrifugal force and people at the equator need have no fear that they will be thrown off the Earth—since nothing is likely to accelerate the motion of the Earth.

Rather should they congratulate themselves, for at the equator a man can jump a given height with less physical effort than is required at any other place on the Earth. This is because the pull of gravity is modified to a certain extent by the speed of 1,000 miles an hour at which the Earth's surface at that point is travelling. Other things being equal, it should be easier, therefore, to put up records for the high-jump at the equator than in other latitudes. Strictly speaking, records made in different latitudes cannot be compared—some form of handicap should be introduced, increasing as the equator is approached!

Gravity is the great force that not only keeps us on the Earth, but keeps the Earth from flying off into space. Its effects are apparent everywhere and it is one of the most important forces in Nature. Without it the universe would "go to pieces". The "laws" of gravitation were discovered by Sir Isaac Newton (1642–1727). According to the story, his attention was directed to the matter by a falling apple in his garden at Woolsthorpe in Lincolnshire.

There are two chief laws of gravitation. The first is that the force of gravity varies directly in ratio to the mass or quantity of matter. This means, that if a mass is doubled its attraction is doubled; if the mass is trebled the, attraction is trebled, and so on. The second law is that the force of gravity varies inversely to the square of the distance between the bodies. This simply means that if the distance between the two bodies is doubled, the attraction is reduced to a quarter, if the distance is trebled, it is only one ninth as great, and so on.

Some curious effects result from these "laws". As the Earth is some 26 miles greater in equatorial diameter than in

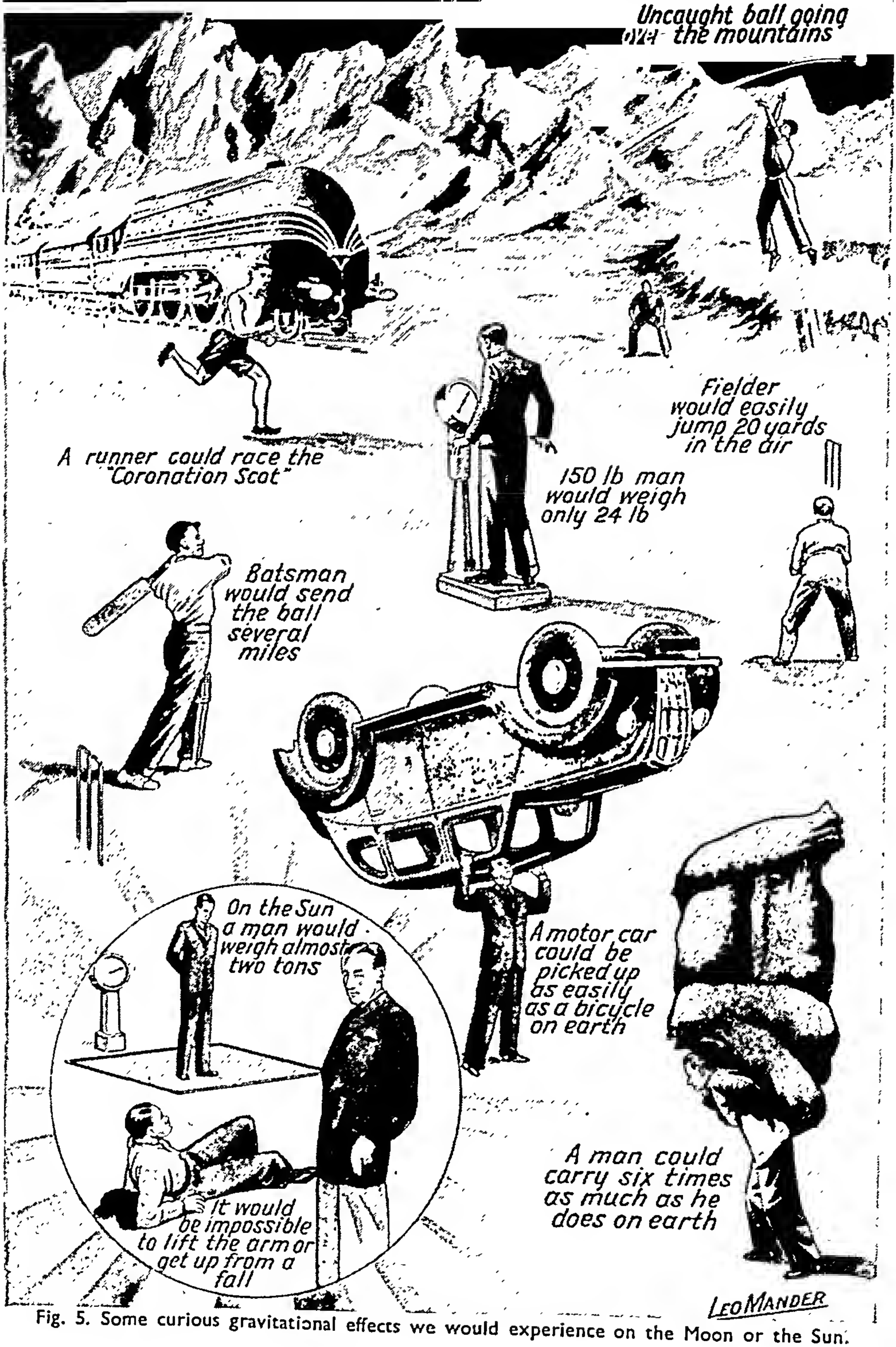


Fig. 5. Some curious gravitational effects we would experience on the Moon or the Sun.

polar diameter, anyone at the equator is some 13 miles further from the centre of the Earth than when at the poles. Consequently, a person will weigh less in Africa than he will in Greenland because of the second law of gravity, already mentioned. Similarly, a person weighing 150 lb. on the Earth would weigh only 24 lbs. on the Moon, and physical effort would be reduced correspondingly. If we can jump 5 ft. here, we could—with the same expenditure of physical energy—jump 30 ft. on the Moon. It would be as easy to jump over a lunar house as it is to spring over a five-bar terrestrial gate. We could there pick up a motor-car as easily as we pick up a bicycle here (Fig. 5).

GALILEO'S FAMOUS EXPERIMENT

Galileo's famous experiment from the leaning Tower of Pisa showed that all bodies fall to the ground at the same speed. A ball of lead and a ball of wood will fall to Earth at an equal speed, if they are of identical diameter and if their surfaces are of equal smoothness. Even if the ball of lead weighs 56 lb. and the wood $\frac{1}{20}$ oz. the two would fall at the same speed, if the friction caused by the air does not differ. When bodies are moving at high speeds, of course, the frictional forces are considerable and must always be taken into account.

A feather and a penny dropped from the same height will not reach the ground together in ordinary circumstances, because the feather is buoyed up by the air, the resistance of which hinders the motion of falling. If the feather and the penny were dropped in a vacuum, however, they would both reach the ground at the same instant. In other words, all bodies will fall to Earth at the same speed except in so far as they are subjected to interference by the air.

The speed at which bodies fall is not a constant one, for a continually-acting force such as gravity will move a body at an ever-increasing speed. This is known as a uniformly accelerated motion. That is to say, a falling body gains speed as it falls, unless resisted by friction. For example a body falling from a height of 1,600 ft. will fall 16 ft. in one second; 64 ft. in two seconds; 144 ft. in three seconds; and so on, as shown in Fig. 6. Its velocity at the end of the first second will be 32 ft. per second; at the end of the second, 64 ft.; at the end of the third, 96 ft.; and so on as shown in Fig. 6. Such a body will reach the ground from a height of 1,600 ft. in 10 sec., and at the time it touches the ground it will be travelling at a velocity of 320 ft. per sec. High explosive bombs dropped from a height of 12,000 ft. will be travelling at over 700 miles an hour by the time they reach the ground—twelve times as fast as an express train!

WHAT GRAVITY MEANS

Gravity holds the Earth in its orbit, the Sun preventing it from flying off into space. The arrangement may be likened to a boy swinging around his head a weight fastened to the end of a rope. So long as the rope is there the weight is held in its path, but should the rope break the weight would fly off to a considerable distance. The Sun is a much mightier body than the Earth and exercises a tremendous pull. It has been calculated that this invisible force is so strong that if a material connection was needed to replace it, this could only be obtained by covering the whole Earth with steel wires set as closely together as blades of grass in a field!

Incidentally, it may be mentioned that as the Sun is gradually parting with its substance, and as its mass is therefore diminishing, its gravitational hold on the Earth must also be growing less.

In other words, the Earth's orbit is correspondingly growing, to an extent that is increasing the distance between the Sun and the Earth at the rate of a yard in a century. This may seem to be an insignificant amount but in a billion years it will amount to several million miles, and will produce far-reaching consequences.

It is interesting to know that despite the flattening of the polar diameter being so comparatively slight, it can be detected by the swinging of a pendulum. A pendulum swings, of course, because it is attracted by the mass of the Earth beneath it. Thus if the Earth were a perfect sphere its attraction would be identical at all places and a pendulum would swing with exactly the same beat at all places on the Earth. In fact, however, the oscillations of a pendulum vary according to the place where the pendulum is situated. These oscillations are more rapid at the poles than at the equator, and would result in a pendulum clock that keeps time at the equator gaining $3\frac{1}{2}$ minutes in a day if taken to the poles. This is because the degree of the Earth's attraction on the pendulum depends on its distance from the Earth's centre.

FOUCAULT'S DISCOVERY

A pendulum will also prove to us that the Earth rotates on its axis, as was first shown in 1851 by J. B. Léon Foucault (1819–68). He suspended an iron ball by a wire 200 ft. in length, from the dome of the Pantheon in Paris. The ball was allowed to swing and at each oscillation it touched a tray of sand, thus leaving a mark on the tray every eight seconds. After a few moments it could be seen that the direction of the pendulum's movement was changing, for the ball marked the sand in a new place (Fig. 7). Soon it appeared from the marks that the whole of the Pantheon

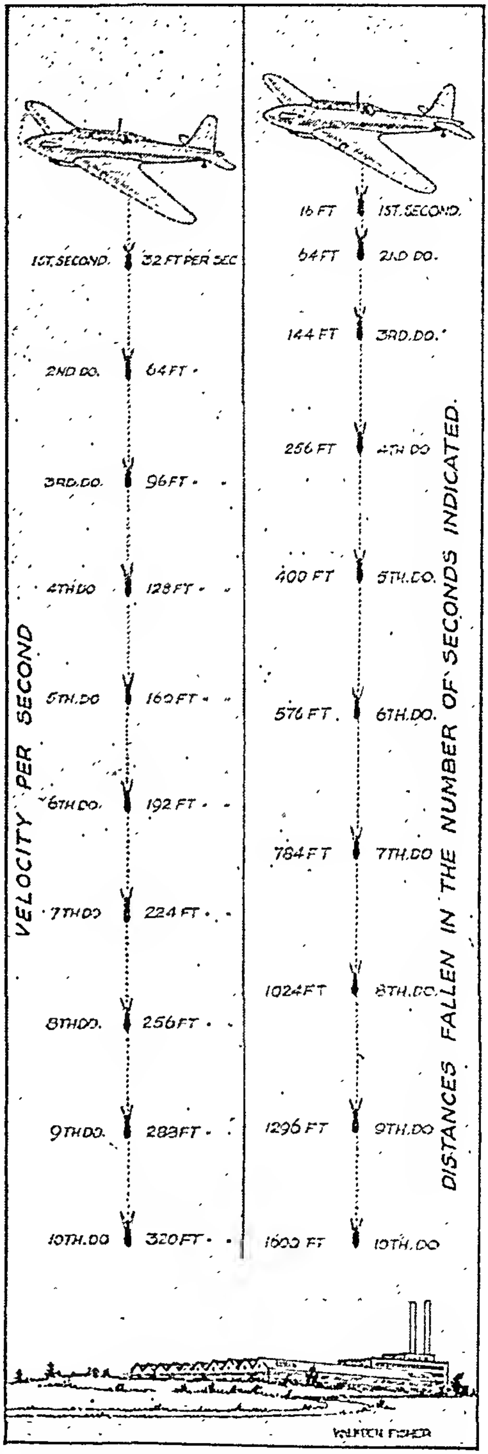


Fig. 6. Speed and acceleration of a falling body.

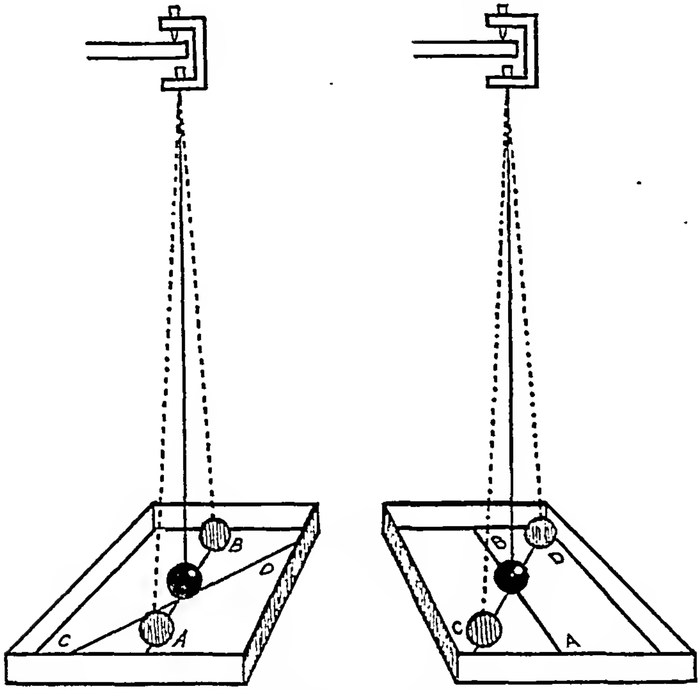


Fig. 7. How Foucault's pendulum demonstrates the rotation of the Earth. At first (left) the pendulum swings from A to B. Then later (right) the direction gradually changes to from C. to D.

The rotation of the Earth has to be taken into account in several ways in daily life. In long-range artillery work, for instance, allowance must be made for the fact that a shell fired to the north or south appears to deviate westward. This is because the Earth is rotating beneath the shell as it travels, exactly as it rotates beneath the freely-swinging pendulum. A practical application of the Earth's rotation is seen in the gyro-compass, which would not work at all if the Earth did not rotate on its axis.

was rotating in an anti-clockwise direction below the swinging pendulum—which, in fact, was exactly what was happening, for the rotation of the Earth had carried it through part of a circle whilst the pendulum was swinging. Incidentally, Foucault's experiment is performed every day in the Science Museum, South Kensington, London, for all to see.

If hanging at either the North or South Poles, a pendulum would indicate that the Earth had turned a complete circle beneath it in 24 hours, or to be more exact, 23 hr. 56 min. 4·1 sec., the length of what is called the sidereal day—that is, the period of rotation of the Earth. The movement would be clockwise at the North Pole and anti-clockwise at the South Pole. At the equator the pendulum would show no movement because, as a moment's thought will make abundantly clear, there is there no rotation in a horizontal plane.

The gyro-compass, or "Iron Mike", as it is often called on board ship, is among the most interesting of the devices with which science has endowed the navigator. The slightest deviation of the ship's head from its course is immediately and automatically corrected by this steering device. With the aid of the gyro-compass one man can steer a large ship: a task which without it would command the attention of half-a-dozen men.

About the middle of the eighteenth century a man named Serson conceived the idea of applying the gyro principle to the compass, but lost his life at sea while carrying out experiments. The first practical gyro-compass was put into operation in 1911. During the World War it was used in warships and submarines, and immediately after the conflict it was adopted first by American commercial craft and then by the mercantile marines of other nations.

CHAPTER 7

TIME AND TEMPERATURE

PERHAPS the most important application of the Earth's rotation is in the measurement of time. The interval between one noon and the next is the solar day, and this is divided into 24 hours, and these again into 60 minutes. In the days before clocks, the passage of time was measured by sundials, noon being when the Sun reached its highest point in the heavens for the day. Although a clock will measure 24 equal hours from noon to noon, it does not agree with a sundial as to the time when the Sun is highest in the heavens at different times of the year, for the clock measures 24 equal hours throughout the 365 days. As the Earth moves at different speeds in its yearly journey round the Sun—later we shall explain why this is so—the sundial and the clock do not exactly agree. The amount of the difference between them is known as the "equation of time."

In olden days people supposed that the Sun moved round the Earth and they determined its apparent pathway among the stars. This belt of stars they called the "Zodiac", from a Greek word meaning "animal circle", because several of the twelve constellations in it are known by the names of animals. Later Copernicus suggested, and Galileo demonstrated, that it was the Earth that travelled around the Sun. It is this movement that causes the stars to rise four minutes earlier each night.

The time taken for the Sun to make its apparent journey through the Zodiac is known as the sidereal year. Its length is roughly $365\frac{1}{4}$ days—actually, of course, this is the time required by the Earth to make a complete revolution in its orbit around the Sun. In determining the length of the year we disregard the odd quarter of a day—which would otherwise cause considerable inconvenience—and give the year the round number of 365 days for three successive years. We give every fourth year 366 days, however, and this is called "leap year", the extra day being gained from the four quarter-days, left over. Thus any year the date of which will divide by four is a leap year.

THE ODD QUARTER-DAY

Without going too deeply into the matter, we may say that the odd quarter-day is actually only of 5 hr. 48 min. 46 sec. duration. As it is about $11\frac{1}{4}$ min. short of a quarter-day of 24 hr., a whole day will be gained in 129 years, irrespective of the allowances made for leap year, and in 400 years this will amount to three days. It was Pope Gregory XIII who decreed, in 1582, that the matter should be adjusted by making only such century years as are divisible by 400 leap years. Thus, although the year 1900 is divisible by 4, the year 1900 was not recorded as a leap year because it is not divisible by 400 and there was no leap year between 1896 and 1904. At the time of this decree there was an accumulated discrepancy of ten days, so Gregory decided that the calendar should be corrected by dropping ten days, the 5th October, 1582, being called the 15th.

The Gregorian Calendar was adopted by all Catholic countries, but the Greek Church and the Protestant nations would not recognise the decree. In 1752, however, England came into line by calling the 3rd September the 14th. In the same year another matter was put

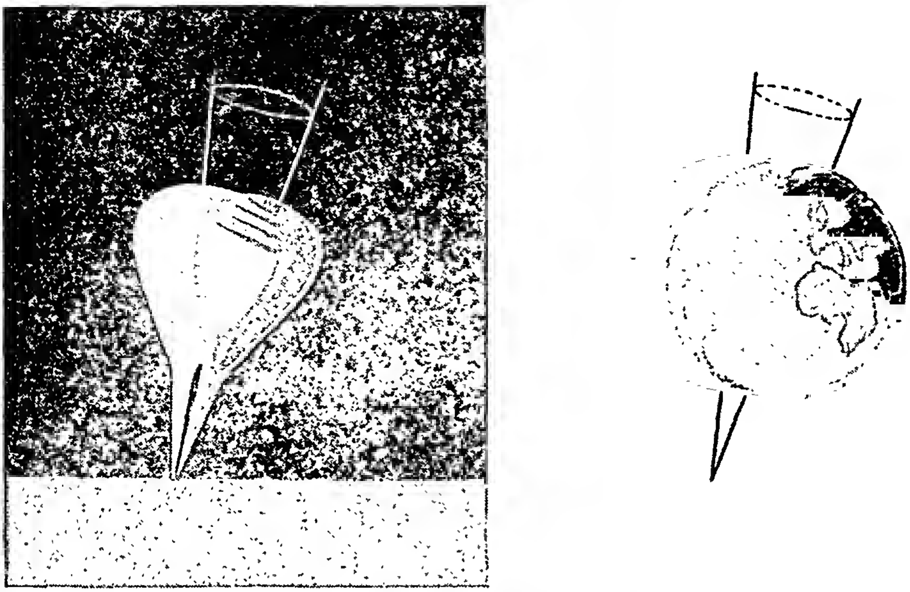


Fig. 1. When a peg-top (*left*) spins, it wobbles on its axis. So does the Earth (*right*). This movement, called precession, takes 26,000 years to complete one revolution. As a consequence of precession, the positions of the Arctic and Antarctic circles are gradually changing.

right when the year was reckoned to commence on 1st January instead of 25th March as had long been the rule. The former change was so resented by many people that there were riots in various parts of the country, the people imagining that they had been robbed of eleven days, and that the Act of Parliament was merely a means of extorting eleven days more rent or interest than they would otherwise have had to pay !

Incidentally, if our present valuation of the solar year is correct, the error in the Gregorian calendar will amount only to one day in about 3,320 years.

Everyone has noticed that as a peg-top rotates on its axis, its axis also slowly rotates as it spins (Fig. 1). This movement, called "precession", is due to the effect of gravity and will continue as long as the speed of rotation is maintained. Now the Earth is spinning in a similar way at a high speed, and—so far as we can tell—as it is in a perfect vacuum, the motion should go on for ever, since there is no friction to retard it. It spins at the rate of one rotation a day, and, like the peg-top, it also "wobbles", or precesses, on its axis. This results in the North Pole rotating in a small circle, so that it points to a new part of the sky as time goes on. The effects of precession are not great enough for us to detect casually, however, for a single rotation requires about 26,000 years to complete.

VARYING SPEEDS OF THE EARTH

We mentioned in an earlier paragraph that the Earth moves at different speeds at different points in its orbit. This is due to the orbit being slightly elliptical and is in accordance with certain laws of motion formulated by Kepler. His second law states that a line drawn from the Sun to a planet moves over equal areas in equal periods of time, no matter whether the planet is travelling over the part of its orbit that is nearest to, or furthest away from, the Sun. Thus, as the orbit of the Earth is elliptical in shape it follows that the Earth must move more quickly when it is near the Sun, as is shown clearly in Fig. 2.

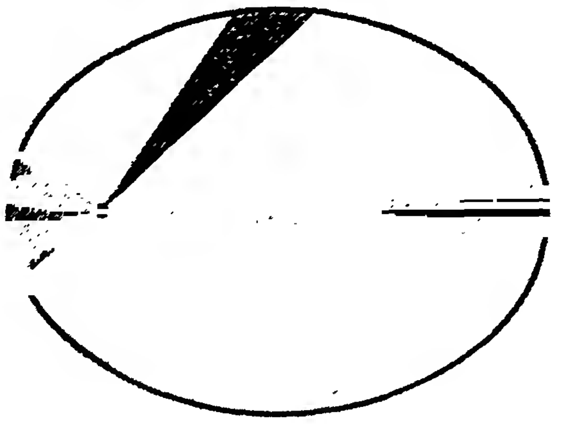


Fig. 2. Kepler's second law of motion states that a line drawn from the Sun to a planet moves over equal areas in equal periods of time. A planet thus moves fastest when it is nearest the Sun.

An ellipse, which is a foreshortened circle, can be drawn by fixing two pins in a drawing board, and passing over them a loop of cotton (Fig. 3). A pencil placed in the loop, so held that the loop is kept tight while moving the pencil, will result in the drawing of an ellipse, the shape of which depends on the distance between the two pins. These pins mark the *foci* of the ellipse. Actually, the Earth's orbit is only very slightly elliptical and only a very little different from a circle. The Sun is at one of the foci.

The distance of the Earth from the Sun varies by about 3,000,000 miles at different points in the orbit. The mean distance is 92,900,000 miles, to cover which it would take a high velocity shell nearly five years. It is a curious fact that the Earth is nearest to the Sun at the beginning of the year, and furthest away in July. It is obvious, therefore, that distance has little to do with the seasons, otherwise we should experience the hottest weather in January and the coldest in July.

The amount of heat received by any

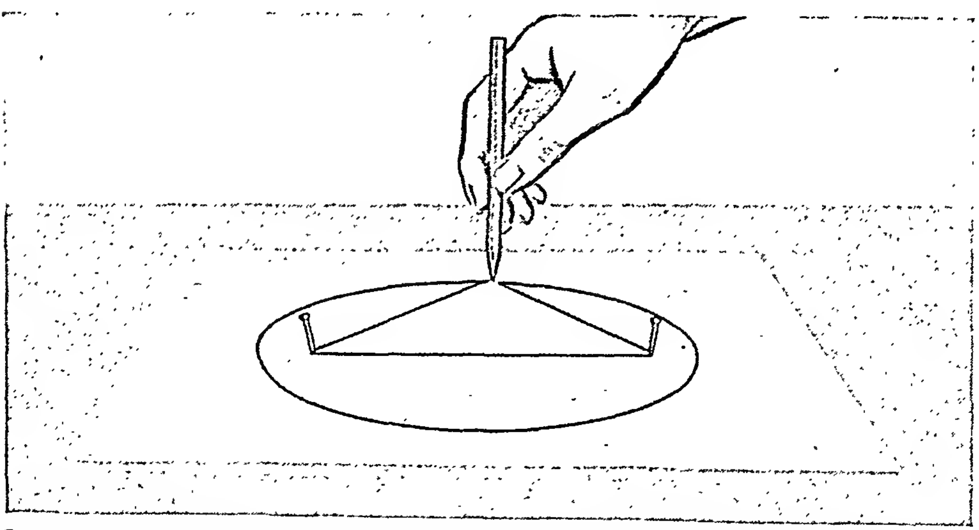


Fig. 3. Drawing an ellipse with two pins and a piece of string. The further the pins are apart, the greater is the degree of ellipticity. The orbit of the Earth round the Sun is not a true circle, but is slightly elliptical, with the Sun situated at one of the foci of the ellipse.

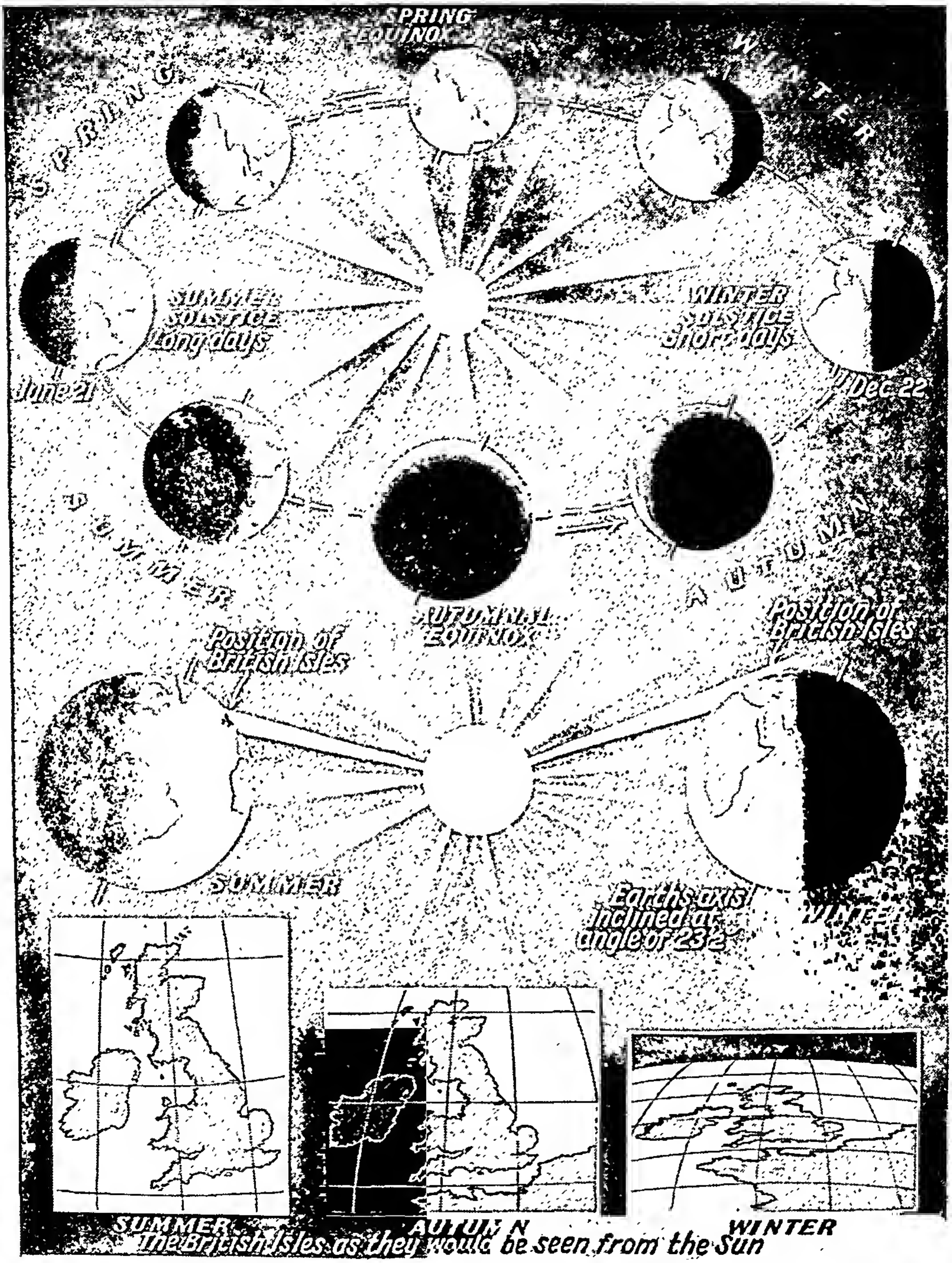


Fig. 4. The seasons depend on the inclination of the Earth's axis.

one part of the Earth's surface is determined much less by the distance the Earth is away from the Sun than by the inclination of the Earth's axis, and whatever may be the position of the Earth in its orbit, its axis is inclined at an angle of 66° 32′ to the plane of the orbit (Fig.4). It is fortunate that the axis is so

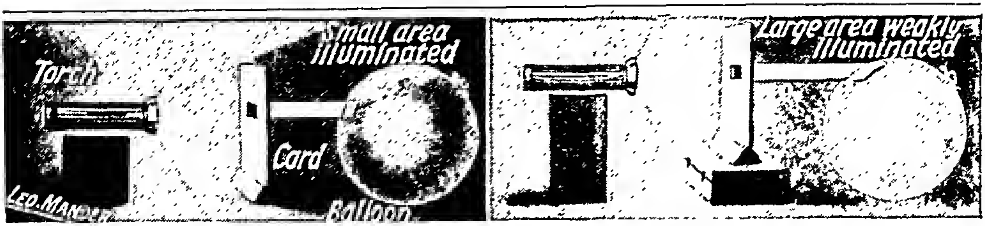


Fig. 4b. The effect caused by the different angle at which the Sun's rays may strike a particular part of the Earth. This effect is shown diagrammatically in Fig. 6.

inclined, for were it always vertical there would be no seasons, and the days and nights would be of equal length all the year round. As a result of this inclination of the Earth's axis, however, only on 21st March and 23rd September are the day and night of equal length all over the world. On these two dates, the north and south poles are equally exposed to the Sun's rays.

After the spring equinox, however, the northern hemisphere inclines increasingly towards the Sun, and the southern hemisphere inclines away from it to a corresponding degree. Spring gives place to summer in the north, and on 21st June comes the longest day, corresponding to 22nd December when there is the longest night. The former is known as the "summer solstice" and the latter as the "winter solstice".

In summer in the northern hemisphere the Sun rises in the north-east and sets in the north-west, whereas in March and September it rises due east and sets due west, but is not so high in the heavens at noon (Fig. 5). In winter it rises in the south-east, sets in the south-west, and at noon is low in the sky. At midsummer, as apparently it has to travel over a large arc of the sky, it is above the horizon for 16 hours; at the spring and autumn equinoxes, for 12 hours; and at midwinter for only

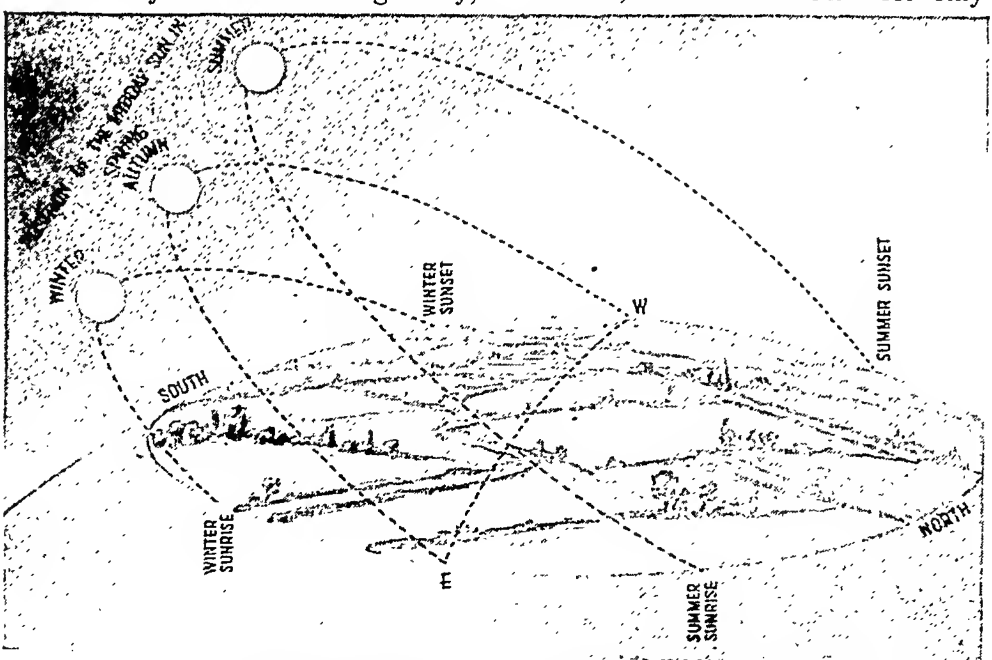


Fig. 5. The difference in the daily path of the Sun during different seasons.

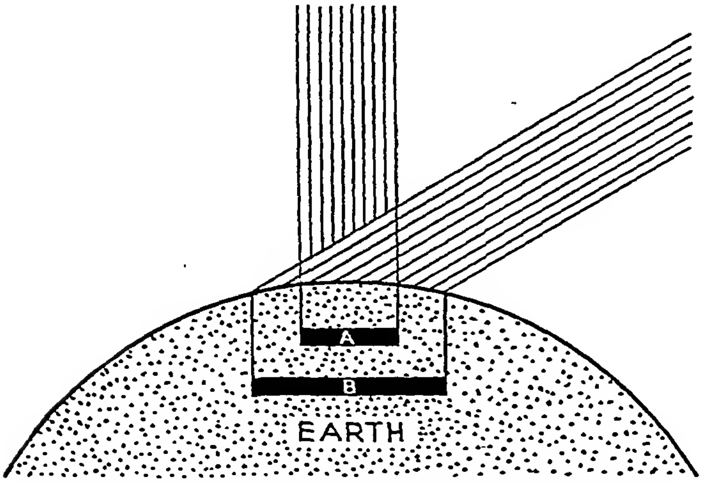


Fig. 6. The difference in area covered by similar beams of sunlight falling on Earth (*a*) vertically, and (*b*) at an angle.

about 8 hours (Fig. 5). During the northern summer, it is winter in the southern hemisphere. After 21st June the days grow shorter in the northern hemisphere and longer in the southern hemisphere, which now receives an increasing amount of sunlight. At the winter solstice there are short days and long nights in the northern hemisphere, and the further north one goes the shorter are the days. At the shortest day the Sun is above the horizon for $7\frac{3}{4}$ hr. at London, and for $5\frac{3}{4}$ hr. in the Orkney and the Shetland Islands.

WHY IT IS HOT IN SUMMER

So much for the periods of time during which the Sun is above the horizon. To explain in greater detail why it is hotter in summer, even though the Earth is 3,000,000 miles further away from the Sun, we may refer to Figs. 4*b* and 6. These illustrate that the amount of heat received at any given place is regulated by the angle at which the Sun's rays fall. When the rays fall vertically on the land we are receiving their full power, but when the rays are inclined—owing to the greater inclination of the Earth on its axis—we receive proportionately less heat, for the same rays have to cover a larger area of the Earth's surface.

We shall be better able to understand this by imagining that we have a beam of sunlight a mile square. If this falls vertically on the Earth it will cover and warm a square mile of land, but if it reaches the Earth at an angle it has to cover an area the smaller sides of which are a mile in length while the other sides are proportionately longer. As there is exactly the same amount of light—and heat—radiation in each beam, it follows that in the latter case a given area of land will receive a smaller quantity than in the former case and that the heat and light will be correspondingly diminished. The principle is illustrated also in Fig. 4*a*.

If the Sun's rays are inclined at an angle of 50°, only 64 per cent. reaches us; at 10°, only 6 per cent. At noon on midsummer's day, in latitude 52° N. the Sun's rays have an inclination of $61\frac{1}{2}°$ to the horizon, whereas in midwinter the inclination is $14\frac{1}{2}°$ to the horizon. Observations at the National Physical Laboratory at Teddington show that there is nine times as much sunlight at 9 a.m. on a June morning as there is at the same hour on a January morning. At noon there is four times as much in June, and at 3 p.m. nearly ten times as much.

Every morning between the winter and summer solstices the Sun rises, and every night it sets, a little further to the north. Every day at noon it reaches a little higher in the heavens, until on 21st June, the longest day, it is above the horizon for about eighteen hours,

rising in the north-east and setting in the north-west. At midnight it is only a little distance below the northern horizon as seen from London. We have only to travel further north to reach the "land of the Midnight Sun". Here, at places situated beyond the 66th parallel of north longitude—such as the northern parts of Sweden, Norway, and Russia—during the summer the Sun does not sink beneath the horizon at all, even at midnight (Fig. 7). Naturally, such a state of affairs is of the greatest assistance to polar explorers, who take full advantage of the long stretches of continuous sunshine. This long period of unbroken daylight is counterbalanced by the long polar night, however, when there are periods of total darkness during which the Sun does not rise above the horizon for months on end. At this time there may be seen wonderful displays of *aurora borealis*, the "northern lights", and the corresponding *aurora australis*, as the display is called in the southern hemisphere.

We may here refer to the fact that some people think there is more moonlight in the autumn than at any other time of the year. This belief is correct and is due to a phenomenon called the "Harvest Moon". The explanation lies in the fact that the full Moon at the autumn equinox is in that stretch of its orbit where it is moving north most rapidly. For the best part of the year the Moon rises some 45 minutes later each night, but when it is moving north the time is diminished,, so that it rises only a few minutes later each evening. It may be that the time of rising is only an hour later in five days instead of nearly four hours (i.e. 45 min.$\times$5). Conversely, at the March full Moon, when the Moon is moving south in its orbit, the times of rising may be quite as much as $1\frac{1}{2}$ hr. later each night.

Fig. 7. _ A picture taken at midnight from Abisko on Lake Tornetrask in Lapland.

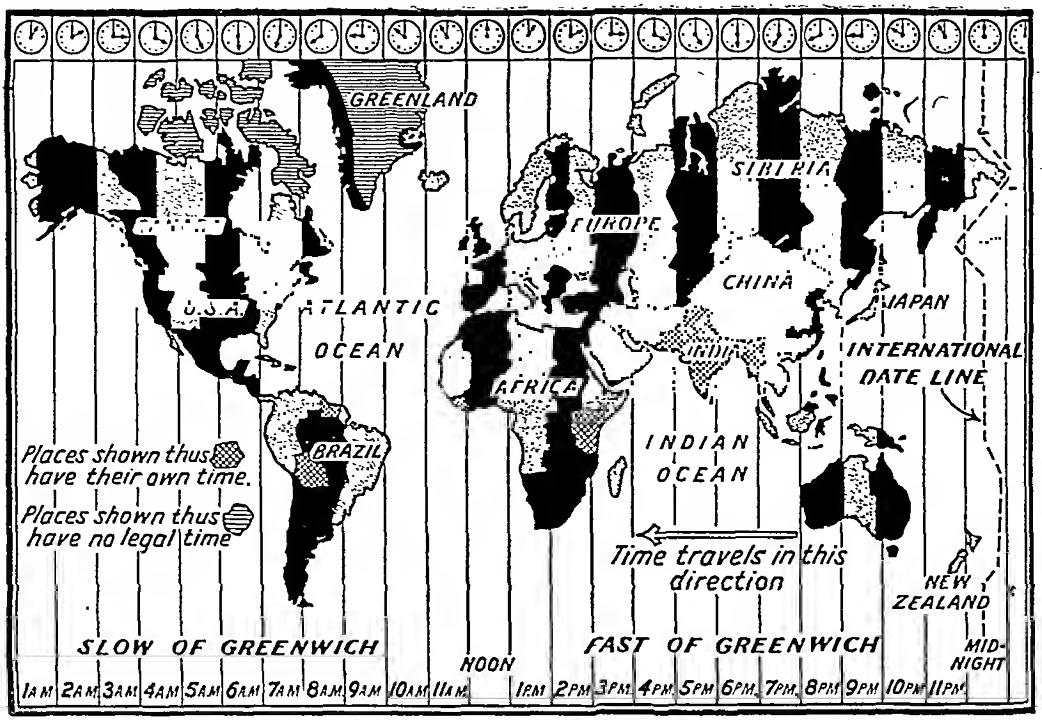


Fig. 8. In 1884 the world was divided into twenty-four time zones, each fifteen degrees apart. There is an hour's difference in time between each line. Some countries do not keep to zone time.

This increase in the duration of the moonlight reaches its maximum when the full Moon is moving north, for it rises about sunset on several successive evenings. It is above the horizon for most of the night, thus allowing the farmers to work longer—should they wish to do so!—than if the night were dark. The Harvest Moon is always the full Moon that falls nearest to the autumnal equinox (23rd September). Often the Harvest Moon is seen just after sunset hanging like an orange ball low in the sky. This is because in early autumn the horizon is mostly clear of mist or cloud.

In the preceding paragraphs we have had occasion to refer to latitude and longitude, and it will be opportune here to make a brief reference to the means by which we are able to define points on the Earth's surface—as, for example, when a geographer wishes to state precisely where a village or town is located, or a captain wishes to say exactly where his ship is on the ocean. For this purpose the Earth's surface is divided by lines of latitude and longitude. The northern and southern hemispheres of the Earth meet at the Equator, which is half way between the poles. Great circles are drawn parallel to the Equator, and are known as parallels. They lie, of course, in planes which are at right angles to the Earth's axis. Corresponding circles drawn perpendicularly to the equator and through the poles are called meridian circles. Do not forget that whereas the parallels of latitude are the same distance from each other all round the Earth, the meridians of longitude all converge at the poles. To fix the position of a town or a ship it is first necessary to know its position with respect to a meridian circle and a parallel of latitude.

All meridian measurements are made from the meridian that passes through Greenwich, this being "longitude 0°". The corresponding meridian at the other side of the Earth may be called either 180° E. or 180° W. Halfway between this and longitude 0° are 90° E. and 90° W. In measuring latitude, the equator is taken as the zero parallel, and the other parallels are respectively north or south latitude, and are also measured in degrees. Latitude is always measured as being north or south of the equator, so that the latitude of New York is written 41° N. The exact position of New York is 41° N. 74° W. Let us now see how the captain finds the position of his ship at sea, where there are no familiar landmarks to give him any indication of his whereabouts.

HOW A SHIP'S POSITION IF FIXED

To obtain the longitude of a ship's position it is necessary to discover the "local time" (Fig. 8) and compare it with the time of day at Greenwich, which is registered by a very accurate clock called a chronometer. The principle is as follows: the Sun makes its apparent daily journey round the Earth from east to west in 24 hours and the Earth is divided into 360 meridians of longitude. Each meridian represents therefore 4 minutes of time. Now, if by the chronometer we know that it is noon at Greenwich and we discover that the local time is 5 p.m. we can calculate our longitude as being $\frac{5 \times 60}{4}$ degrees east, because we are 5 hours (300 minutes) ahead of Greenwich and 4 minutes represents one meridian of longitude. We are in fact in longitude 75° E. If the local time were 7 a.m. we should be in longitude 75° W. Local time is determined on the sundial principle by calculating by means of a compass the direction of the Sun from the ship.

The principle of latitude is as follows: if the Sun is directly overhead at the Equator, then the angle made by the Sun at noon, your ship and the horizon will, if subtracted from 90°, give the latitude. The Sun however is only overhead at noon at the Equator on 2 days of the year; therefore, to find correct latitude, the angle between its actual position in relation to the Equator and its position were it directly overhead must be added to, or subtracted from, the latitude found as already described. This angle has been carefully calculated for every day in the year and is published in tables in the *Nautical Almanac.*

To find the altitude of the Sun—and so that angle of Sun, ship, horizon—a sextant (Fig. 9) is employed. The sextant telescope must be so held that a line from eye to horizon passes through the edge of the mirror. The arm of the sextant is then moved so that the upper mirror reflects the sunlight on to the same edge of the lower mirror. From the scale can then be read the angle between the mirrors. This angle, doubled, gives the required figure.

TEMPERATURE IN THE ARCTIC

If we draw a circle of $23\frac{1}{2}°$ radius around each pole we shall include in it the polar regions. Over extensive areas of both the Arctic and the Antarctic (Fig. 10) are great masses of perpetual ice and snow that decrease only a little during the summer and fully regain any loss during the winter.

In the north polar regions the temperature-line does not run truly parallel to the Arctic circle, for the great masses of land in the northern hemisphere influence the temperature. In the southern hemisphere, however, where there are no continents close to the polar regions, the temperature-line runs roughly parallel to the line of latitude.

Although the Sun is above the horizon

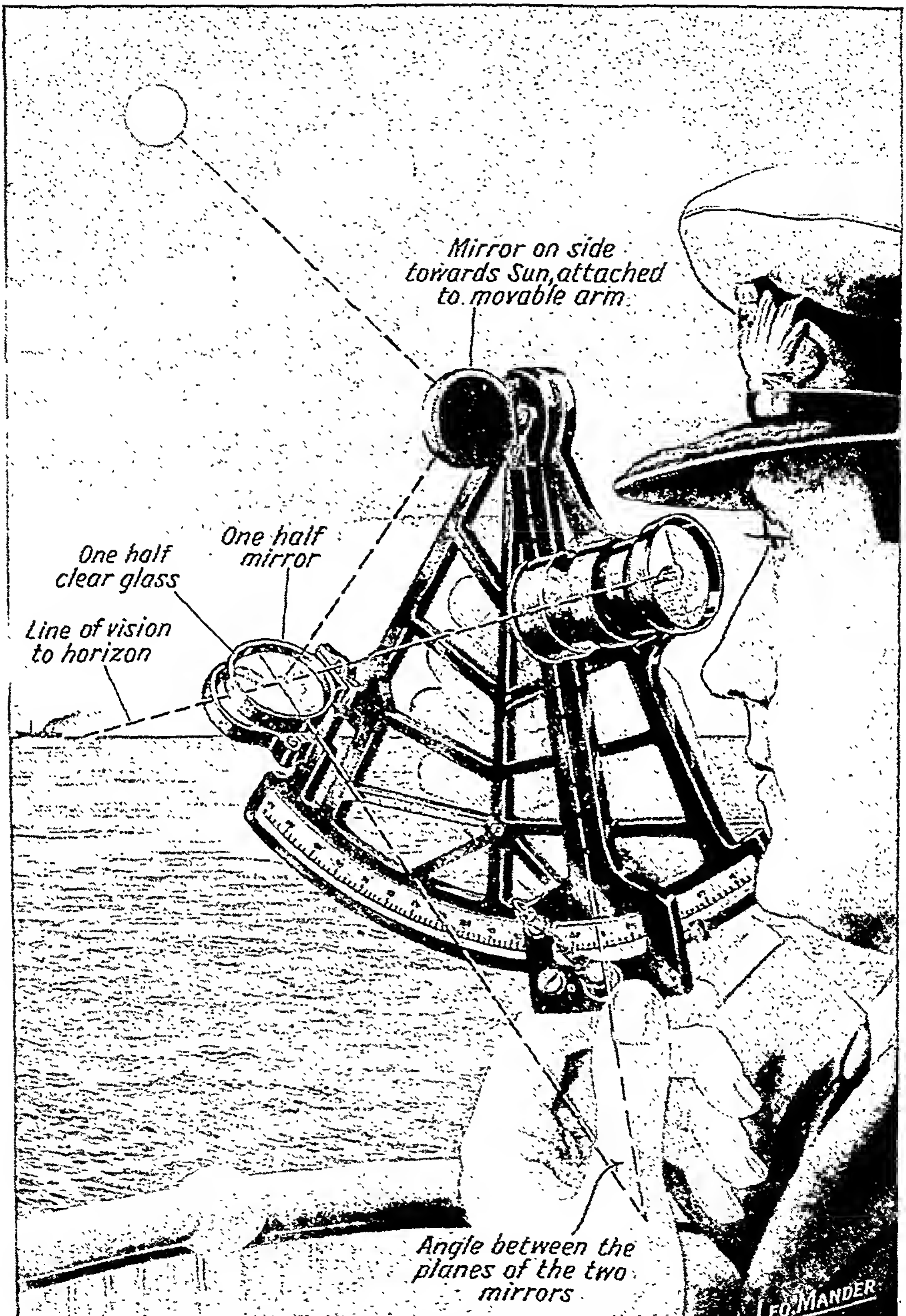


Fig. 9. How a sextant is used to find the angle of the Sun's altitude. (See text).

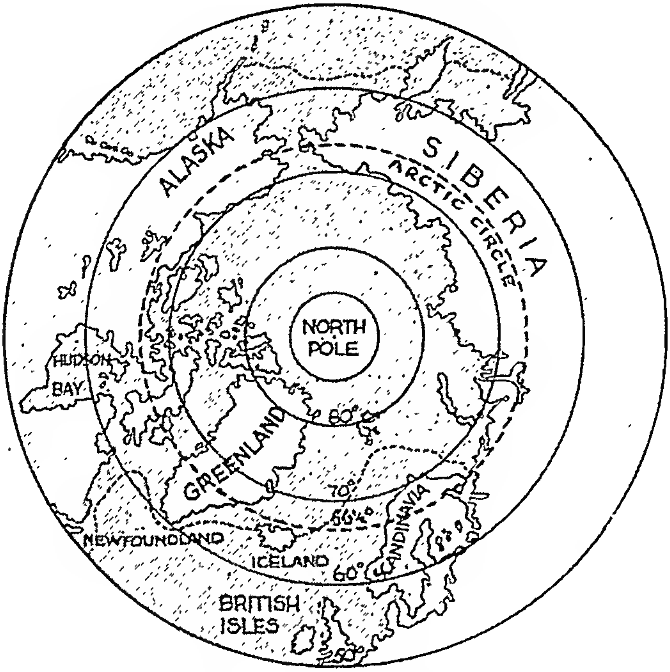


Fig. 10a. The Arctic regions.

at the poles for six months continuously, it is never really hot there, because of the extremely oblique angle at which the rays reach the Earth, as explained by Fig. 6. At the poles, the Sun never rises to more than $23\frac{1}{2}°$ above the horizon, so that even in the most favourable of circumstances, the Sun is only about as powerful as it is in England at sunrise or sunset.

Another reason for the low temperature of the polar regions is that that a large amount of the heat is taken up in melting the ice and snow of these regions, and the long winter of six months further tends to counteract the effects of the long summer daylight, which are very slight in any case owing to the Sun's low altitude.

The Poles do not, however, give us a record for low temperature, for the lowest air temperature yet recorded for polar zones (−76° F.) was exceeded by the −94° F.—or 126° of frost—recorded at Verkhoiansk in Eastern Siberia, just outside the Arctic circle. The average January temperature at Verkhoiansk is −56° F. or 88° of frost. Before the War the Russians used this region as a place of exile for political suspects. The horror of going to the place and the

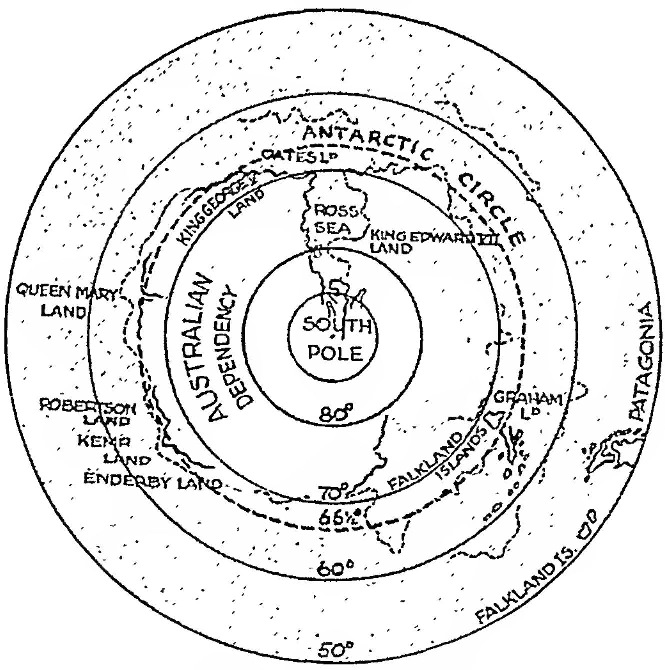


Fig. 10b. The Antarctic regions.

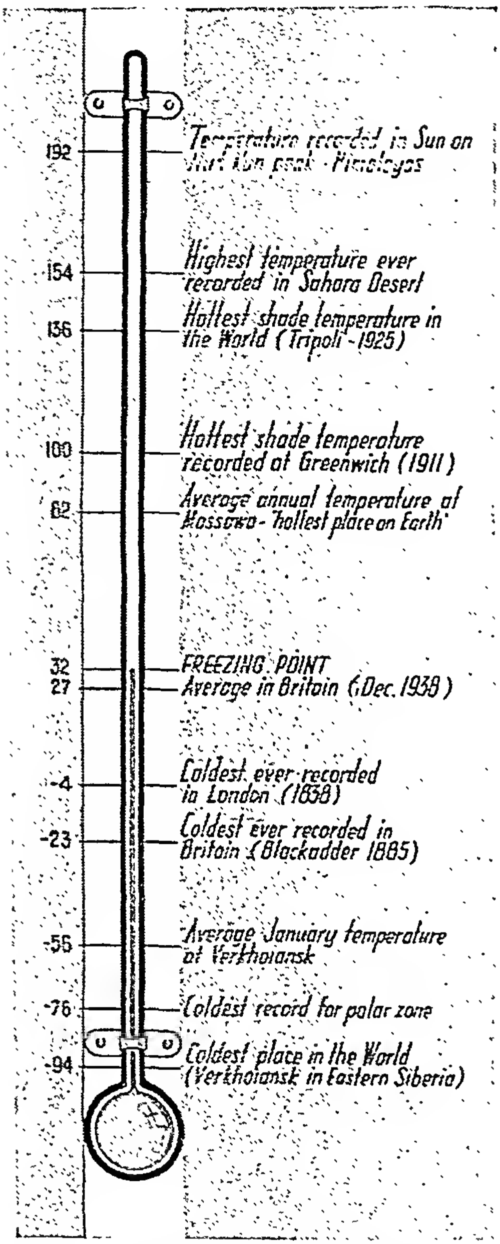


Fig. 11. Contrasts in temperature. The world's hottest and coldest places

agonies of those doomed to live there, in 100° or more of frost, can be better imagined than described. The Soviets have settled people in this region, too, though probably not in the coldest part. When they began to build houses, they found that the walls fell down, because the heat of the house stoves thawed the earth beneath the floors. This had never been thawed before, so it brought about a subsidence. To-day, the floors are raised up, thus effectively insulating the soil from the warmth of the houses.

At Irkutsk in Siberia (50° to 52° N. Lat.) the mercury freezes as early as November. Because of this fact, temperatures such as these in Siberia cannot be measured with an ordinary thermometer and instead they are taken with a spirit thermometer which will not freeze at any temperature to which the atmosphere can fall.

On the whole, the Antarctic appears to be colder than the Arctic, at any rate south of latitude 70° S. The fact that the summers generally are colder accounts for the lack of vegetable and animal life in the Antarctic as compared with the Arctic regions.

HOW MAN FIGHTS COLD

During December 1938 Britain had a spell during which the temperature averaged 27° F., or 5° below freezing-point. At this time the temperature in Moscow was −20° F., or 46 degrees lower than that of Britain. In such places as Moscow everyone is prepared for the cold—boots are made of felt, and fur coats and hats are common even among comparatively poor people. By law apartment houses have to be heated from 1st November to 1st April every year—not only the rooms but the staircases also. Then, too, the windows are double and everyone buys putty to fill in all the cracks. The doors fit tightly and are covered with felt; if they were not they would show a layer of frost even on the inside. Some streets have special large-scale heating systems to combat the cold, steam from a central station coming through pipes, like the gas, to warm several blocks of houses.

The lowest temperature ever recorded in Britain occurred in February 1885 when the thermometer at Blackadder in Berwickshire recorded $-23°$ F., or 55° of frost. This was so far below the previous lowest known ($-17°$) that meteorologists were inclined to doubt the reading, but it was subsequently confirmed by observations in surrounding places. The lowest temperature ever known in London was the $-4°$ F., or 36° of frost, recorded a century ago in the terribly severe winter of 1838. The lowest temperature of recent years was 4° F. recorded at Kew in 1931. Incidentally the highest shade temperature ever known in London was 100° recorded at Greenwich.

Fig. 11 shows diagramatically some of the temperatures we have mentioned, and also some other extreme temperatures.

Expeditions to the polar regions have long held a peculiar fascination for explorers. As early as 1497 John Cabot tried to discover a North-West passage around America to India.

THE NORTH-WEST PASSAGE

In 1850 McClure, in attempting to discover the fate of the Franklin Expedition, found a passage through to the Pacific, and named it Prince of Wales Strait. He was imprisoned in the ice at Melville Sound and was rescued by McClintock. Actually the voyage through the North-West passage was not made until comparatively recent years (1903–05), when the redoubtable Roald Amundsen sailed through in his small ship *Gjoa*, in a voyage that took three years to accomplish. Similarly, the North-East passage, along the northern coasts of Europe and Asia to the Pacific, was not actually navigated until 1879, when the Swedish explorer Nordenskjöld made the successful voyage.

The names of those who have carried out important explorations in the Arctic regions are familiar to all of us—Frobisher, Davis, Bylot, and Baffin were among the earliest, to be followed by Ross and Parry in 1818, and the unfortunate Franklin in 1845, to learn whose fate Ross (1848), McClure (1850), McClintock, and others voyaged to these regions. Then came Nares (1875) and Greely (1881) who reached "furthest north" (83° 24′) only to be eclipsed by Nansen (1888), who approached within 260 miles of the Pole. In 1906 Commander R. E. Peary of the U.S. Navy reached 60 miles nearer, and three years later had the honour of being the first man to reach the North Pole on 6th April, 1909.

EXPLORING THE ANTARCTIC

Exploration in the Antarctic wastes has always been more difficult than in the Arctic. Whereas the explorers in the north are able to replenish their food supplies from time to time from the oxen, reindeer, seals, fish and other animals that live there, those in the Antarctic have not had this advantage and have had to carry all their food. The discoveries of Ross (1839–43) seemed to show that the Antarctic was an impenetrable waste of ice, swept by storms of a violence unexampled elsewhere, and presenting to the open sea an ice wall hundreds of feet in height. The first Antarctic explorer was Pierre Bouvet, a French naval officer, who attempted to find the "south land" in 1739. In 1774 Cook passed the 70th parallel, reaching 71° 10′, and Ross in 1842 penetrated the ice pack and reached 78° 10′. He found further progress barred by a huge wall of ice, which he called the Great Ice Barrier, and sailed eastward along it for 450 miles vainly looking for an opening.

Actually he was looking at the huge cap of ice that covers the whole of the

South Polar regions. This ice cap has at times been variously estimated to be between ten and twenty miles thick, but investigations into the properties of ice and the relations of its melting and freezing point to temperature and pressure, have suggested that such a thickness is impossible. It is assumed that the ice cap rests on rocks the temperature of which is only half a degree below freezing point. If this is so, then the greatest thickness of ice probably would not exceed 1,600 to 1,800 ft. and this is only a little more than the greatest thickness that has been observed in the Great Ice Barrier.

THE GREAT ICE BARRIER

This great perpendicular wall of ice is probably 1,500 ft. thick, rising some 200 ft. above and sinking some 1,300 ft. below the level of the sea. It moves like a huge glacier at a rate of about 100 ft. a month. When it reaches the sea and is pushed out into depths of 400 fathoms (2,400 ft.), large masses are broken off and form ice-islands or icebergs. Captain Scott, who reached an altitude of 9,000 ft. at a distance of 142 miles from the Great Barrier, formed the opinion that the Ice Cap was at one time of much greater extent than it is now.

In 1899, C. E. Borchgrevink, the Norwegian, spent the winter on the mainland of the Antarctic continent, being the first person to do so. Three years later Captain R. F. Scott, R.N. reached latitude 82° 17′, about 463 miles from the Pole, but after suffering great privations was forced to retrace his steps. In 1909, Lieutenant Ernest Shackleton R.N. decreased the distance to 97 miles, when failure of supplies necessitated a retreat. It was left to the Norwegian, Captain Roald Amundsen, to win the race for the coveted honour by reaching the Pole on 14th December,

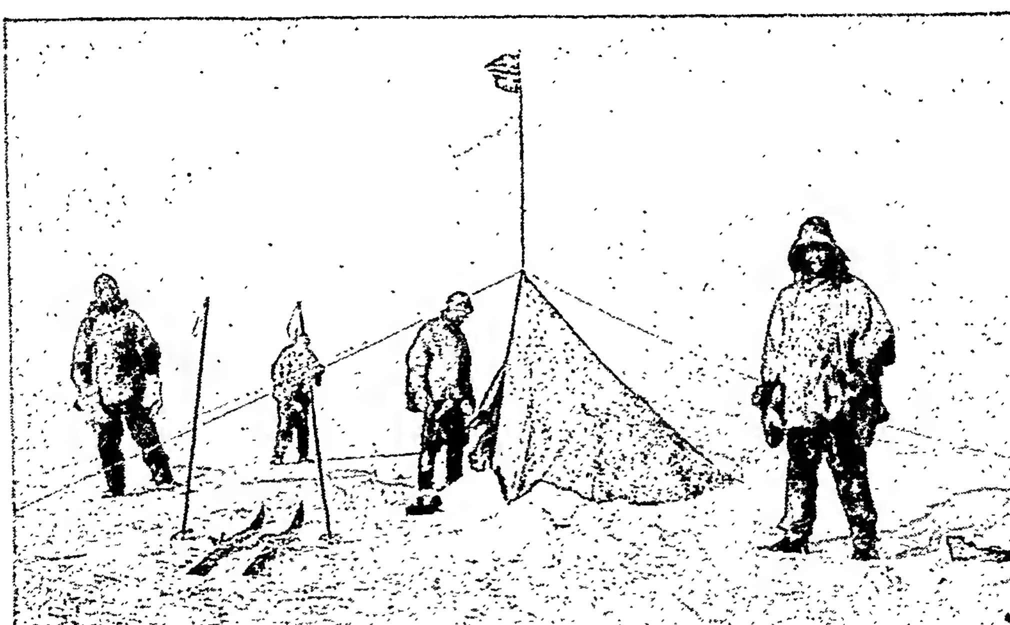


Fig. 12. Amundsen's tent at the South Pole. Scott's party reached the Pole on 17th January, 1912 only to find that Amundsen had managed to forestall them by a month, for he had reached it on 14th December, 1911. The British approached the Pole by a different route.

Fig. 13. The first Englishmen to reach the South Pole. From left to right, Dr. Wilson, Lt. Bowers, Petty Officer Evans, Capt. Scott and Capt. Oates. They are standing in front of the snow cairn they erected. On the right of the party is Amundsen's Norwegian flag.

1911. This was just a month before the British expedition, under Scott, reached the same goal, each expedition having approached the Pole at the same time but from different directions (Fig. 12). This is not the place to enter into details of the tragic fate of the intrepid British explorers—Scott, and his companions Wilson, Oates, and Bowers—who laid down their lives in the conquest of these great fields of ice (Fig. 13).

The extreme cold encountered by Arctic explorers, and those who live in such places as Siberia, has several curious effects. From them we learn that temperatures far below those that man was meant to bear affect many parts of the body, with unexpected results. If you wink for a few seconds your eye "glues up". If you have a beard you frequently cannot open your mouth, because the moisture in your breath freezes together the strands of beard on your upper and lower jaws. If you put out your tongue it freezes to your lip. If you put up your hand to "blow hot" and release your tongue, your hand freezes to your face. If you take off your glove your hand will freeze, and if you plunge the hand into water to thaw it, it will freeze the water instead. If you put a piece of metal to your flesh it will make a wound resembling a burn.

THE WORLD-FAMOUS "OLD FAITHFUL" GEYSER.

"Old Faithful", the famous geyser in Yellowstone Park, U.S.A. has regularly spouted for four minutes every 60–80 minutes to a height of 150 feet. Details of its working are shown on page 132.

CHAPTER 8

THE CRUST OF THE EARTH

THE crust that surrounds the Earth is probably about 20 or 25 miles thick and is composed of three main classes of rocks. The igneous rocks were, as their name implies (Latin: *ignis*, fire), formed from material that was liquified by great heat. These rocks—generally composed of quartz, hornblende, felspar, or mica—are crystalline in structure. If the crystals are large, this means that the cooling took place slowly, but if they are small, then the cooling was comparatively rapid. Of these igneous rocks the best known is granite; it is composed of crystals of felspar and mica bound together by quartz.

There are two kinds of igneous rocks, plutonic and volcanic. In Greek mythology Pluto was the god of the underworld, and the rocks found at great depths below the Earth's surface have been called plutonic after him. They generally consist almost entirely of large crystals, packed closely together because of the pressure at the great depths at which they were formed; this also accounted for their slow rate of cooling. Granite (Fig. 1) is a typical example of plutonic rock. The second kind, called after Vulcan the god of fire, were formed near the Earth's surface, or perhaps forced through the Earth's crust by volcanic action. Basalt (Fig. 2) is a good example of the volcanic rocks, which are composed partly of crystals and partly of a kind of glass. Their rate of cooling was much more rapid and did not allow of all the molten material turning completely into crystals.

SEDIMENTARY ROCKS

Leaving now the fire-formed rocks we come to the sedimentary rocks (Latin: *sedeo*, settle), formed from sediment washed down by rain and water, and deposited, in prehistoric times, at the bottom of what were then seas. The particles composing this sediment settled

Fig. 1. Granite is only formed deep in the Earth, and to produce this outcrop on Haytor, Dartmoor, a great mass of material must have been removed.

Fig. 2. Basalt cliffs near Crayborough. The Roman wall runs along the summit. Basalt is a volcanic rock, composed partly of small crystals and partly of a glass-like substance.

down in the sea and formed layers, or strata, of rock (Fig. 3). Sometimes these stratified rocks are composed of the remains of living organisms that lived in the seas. When these tiny creatures died their minute bodies or shells sank to the bottom of the ocean and formed these deposits. They were so numerous, and the period over which they existed so long, that often these deposits are hundreds of feet thick. Limestone is an example of a rock formed from once-living organisms.

Even to-day the formation of coral

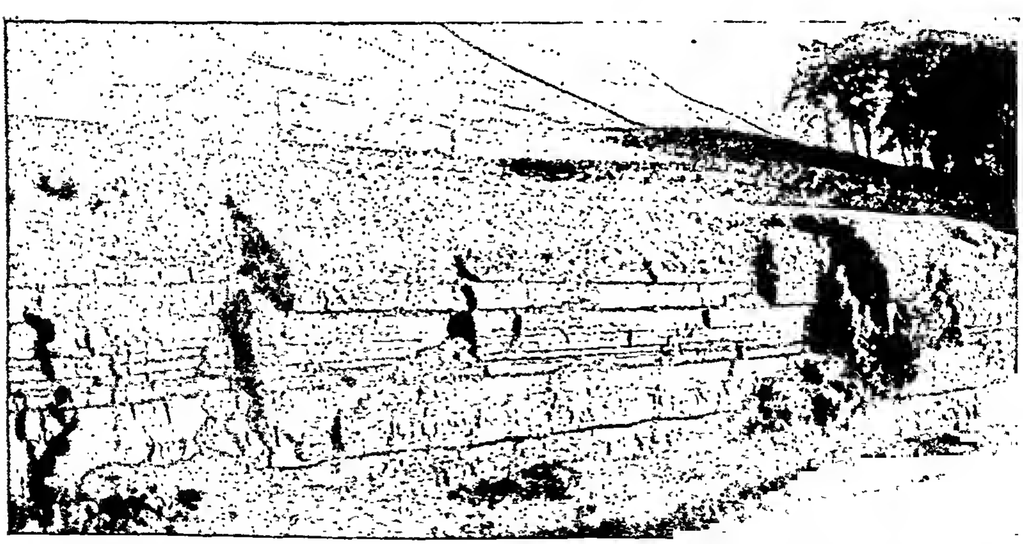


Fig. 3. Stratified rocks in Swaledale, Yorkshire, showing the horizontal layer formation as laid down in prehistoric seas. Later the rocks were lifted to their present position.

reefs—a kind of limestone—is going on, for large colonies of tiny creatures extract the mineral matter in sea water and build it into hard skeletons that act as a foundation for other corals to build on. Thus a coral reef is formed, the sea depositing carbonate of lime between the individual skeletons, so that eventually the whole forms a compact mass of rock. Sometimes the particles of sedimentary deposits are cemented together by mineral deposits deposited at the same time or introduced later by percolating water. In sandstone rocks, for instance, the rounded grains are cemented by carbonate of lime, oxides of iron, and other substances that sometimes affect the colour of the deposit so that we may have yellow, brown, red, or even green sandstones.

The third type of rock, the metamorphic (Greek: *meta*, "change" and *morphe*, "form") originally belonged to either the igneous or the sedimentary class. Having been subjected to intense heat or pressure it has undergone a complete change so that its original features have been obliterated. Mud deposited at the bottom of the ocean normally becomes a solid mass of clay or shale, but if subjected to great pressure it becomes greatly hardened and changed into slate (Fig. 4). Similarly, by intense heat or pressure the igneous granite may be changed into metamorphic gneiss; sandstone into quartzite; limestone into marble; and so on.

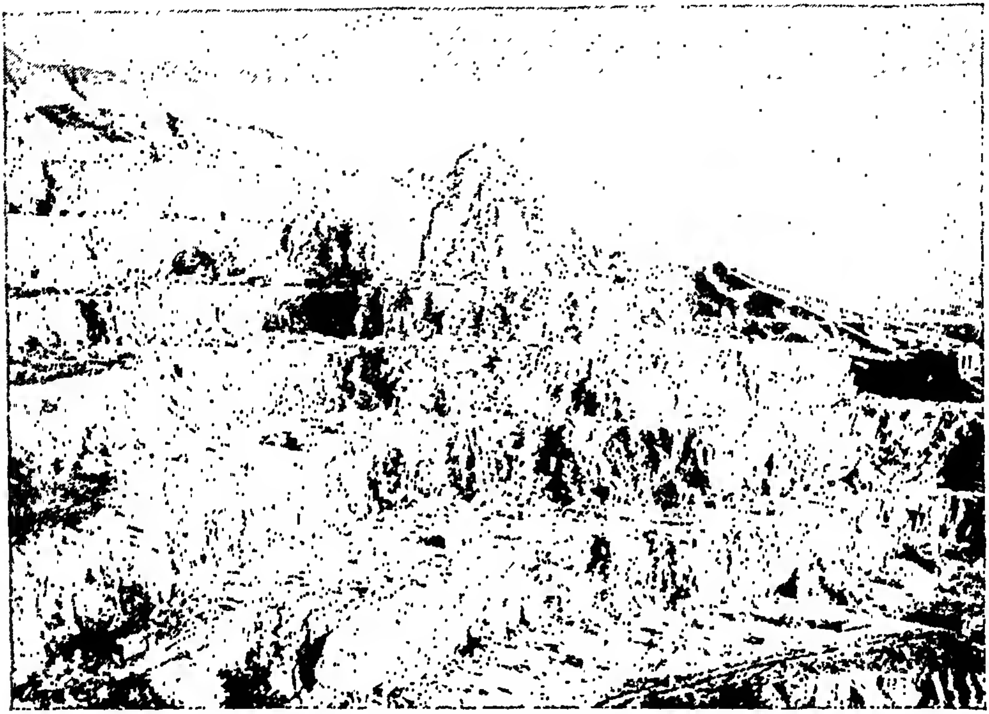


Fig. 4. Slate quarries at Llanberis, North Wales. The slate was once a great deposit of mud on the bed of a prehistoric sea, but land movements have lifted it far above sea-level.

It is of such materials as these that the Earth's crust is composed. In all there are about 850 differently named rocks, including the various sands, clays, and gravels. All belong to one or other of the three great classes we have mentioned earlier in this chapter.

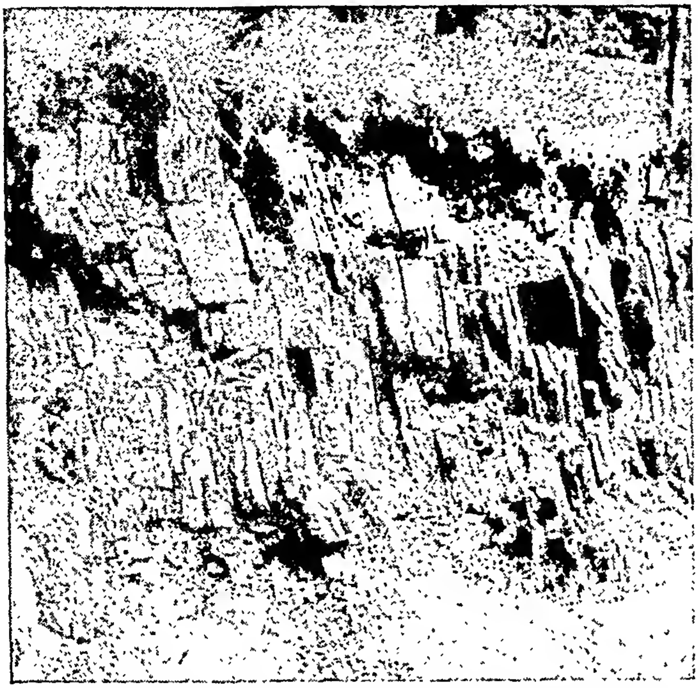


Fig. 5. These almost vertical layers of shale rock near Buttermere were once horizontal layers of clay. They assumed their present position through movements of the Earth's surface.

been formed there; its presence is due to the fact that it has been lifted by earth-movements and that the overlying material has been removed by denudation.

Sometimes, as a result of these earth-movements, sedimentary rocks have been tilted completely from their original horizontal position and now lie at an angle, or "dip", inclined more or less to the horizontal (Fig. 5). Sometimes the enormous pressure arising out of the movements has caused rocks to be bent or folded over or around other rocks, giving the strata an arched appearance. Some good examples of such folding are to be seen in the sandstones at the Cobbler's Hole, Dale, Pembroke; in the schists (slaty rocks) at Almwch, Anglesey, and at Holyhead; in the quartzite at Glen Nevis in Scotland; in the limestones

It is perhaps fortunate that there have been considerable movements in the crust. If this had not been so we should not know very much about the older rocks, for in the ordinary course of events they would lie far below the more recent rocks. These earth-movements, and the denudation—or washing away by rain and other causes—of the surface rocks have resulted in some of the older rocks being exposed at the surface in some places. For instance, on Dartmoor we see granite (Fig. 1), and this we know is a plutonic rock cooled at a great depth below the Earth's surface. That it is now found at the surface does not indicate that it has

Fig. 6. Contorted limestone rock on the shore at Scremerston, Northumberland, clearly showing the different strata.

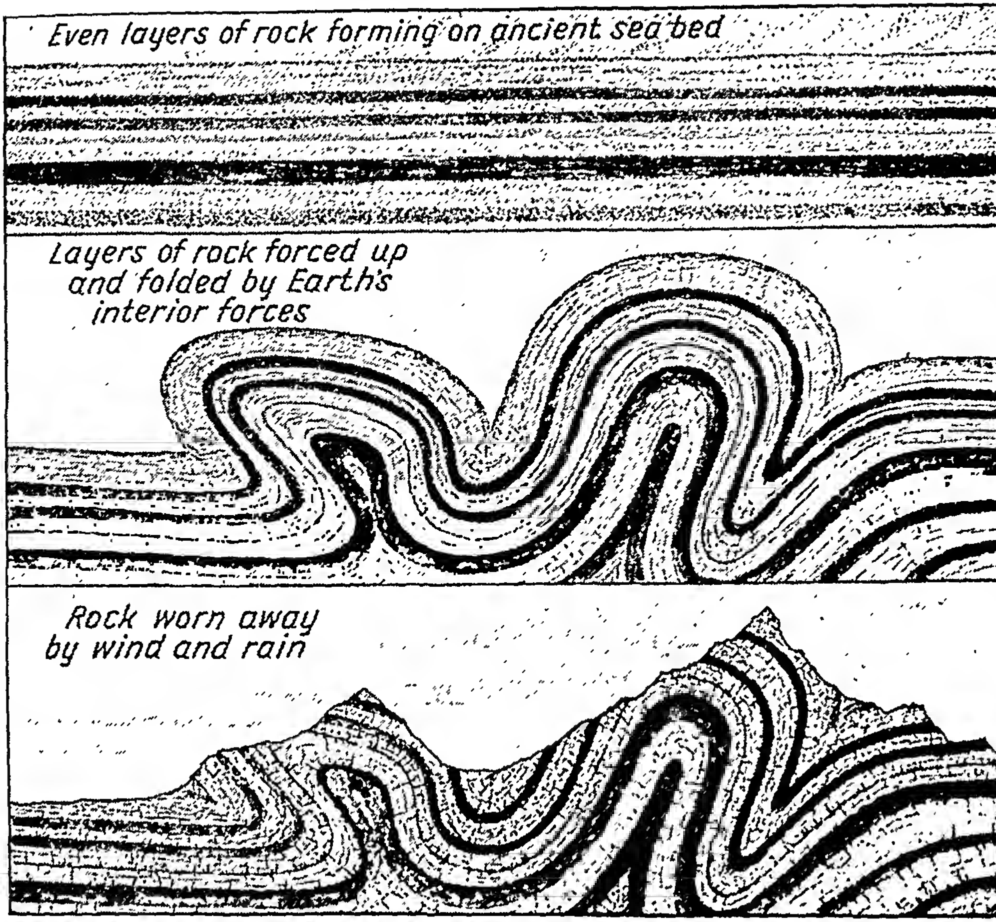


Fig. 7. How mountains are formed. In prehistoric times they formed part of the ocean bed ; then movement of the Earth's crust forced them upwards, to be worn away later by the weather.

at Scremerston, Northumberland (Fig. 6), and elsewhere. Fig. 7 illustrates diagramatically how what was originally a level layer of rock on the bed of the sea may be first arched and finally forced into jagged mountain shapes.

Despite the alterations, caused by earth-movements and denudation, in the original order of the rocks it is possible to identify the period to which they belong by their constitution and by the fossils they contain. A fossil may be either the actual remains of some animal that lived in a bygone age and was trapped in the rock when it was being formed, or it may be the imprint of an animal or plant preserved in the rock. Each stratum of rock has its own particular fossils, and similar fossils are found in similar rocks in all parts of the world. Fossils do not enable us to tell the actual age of the rocks in which they are found, but they do give us some idea of their relative ages. In the oldest rocks there are no fossils, for life did not exist on the Earth at the period when they were formed.

As the earliest forms of life appear in those rocks that were formed from sand, mud, and gravel, it would appear obvious that life first existed in the sea. One of its earliest forms is preserved in the

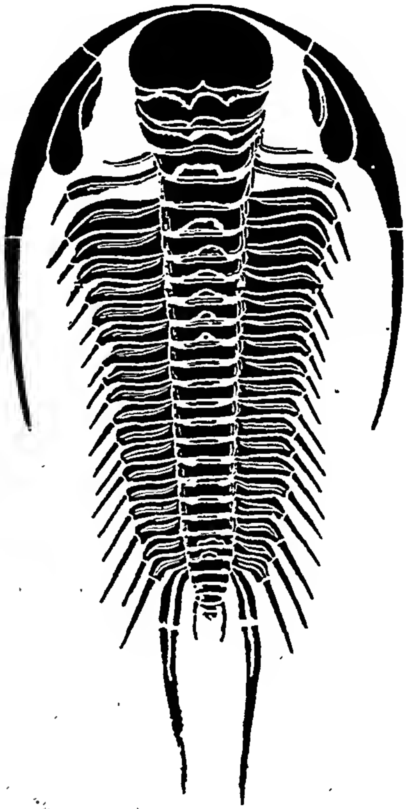


Fig. 8. Fossilised remains of a Cambrian Trilobrite, one of the earliest forms of life.

fossils known as graptolites (Greek: *graptos*, written; and *lithos*, stone) because they have the appearance of writings or drawings on stone. Although they were animals, they lived fixed to the ground like plants. Other early forms include corals, crinoids or sea-lilies, and trilobites, which were somewhat like the king-crabs of to-day (Fig. 8). In the next rocks fishes appear —first shell-fish more or less shrimp-like, followed by true fishes that begin to occur in increasing numbers (Fig. 9).

In the later rocks are the fossils of all manner of animals and plants that lived in the long geological periods. Where the pressure of the rocks has been gradual their remains have been perfectly preserved in a marvellous way. Not only does this apply to hard objects, such as shells and bones, but to muscles and other soft tissues, and to fruits and leaves (Fig. 10). Even spores of ferns (Fig. 11) and pollen grains have left a perfect record in the rocks. Ripples formed by the sea in the prehistoric sand, footprints of prehistoric monsters, and even the imprints of prehistoric raindrops (Fig. 12) are preserved and give up their secrets to the enquirer into science's mysteries and marvels.

COMING OF THE AMPHIBIAN

Limitations of space prevent us from making more than a brief reference to some of the more interesting of the creatures whose remains have been found in the rocks. It would appear that the earliest forms of life were followed by crab-like creatures and then by fish. After these came the amphibians

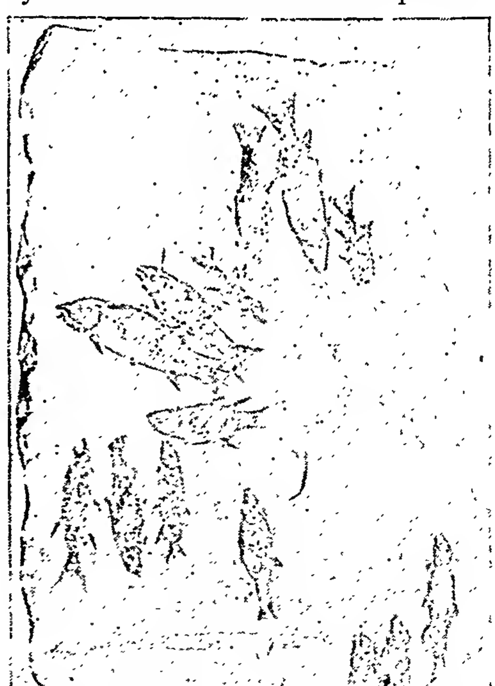


Fig. 9. Fossil fish, millions of years old. The delicate markings of the scales have been perfectly preserved. These fish lived in the Triassic Age.

Fig. 10. A beautifully preserved fossil of a scaly tree, the Lepidodendron Velthimainum. Substances with soft structures such as plants, have been preserved where pressure has been gradual.

—these creatures that were capable of living both on land and in water. At one time these were abundant, but they are now nearly extinct, being represented only by the frogs, toads, newts and salamanders.

The amphibians were followed by giant reptiles—the saurians or lizard-like creatures. Of these the commonest appears to have been the Ichthyosaurus, or fish-lizard, which sometimes grew to be as large as a whale, with its four swimming paddles, and long pointed tail (Fig. 13). Its enormous eyes were protected by bony plates and some 200 teeth adorned its alligator-like jaws. Fossils of Ichthyosauri have been found all over the world in great numbers, and are plentiful in Britain.

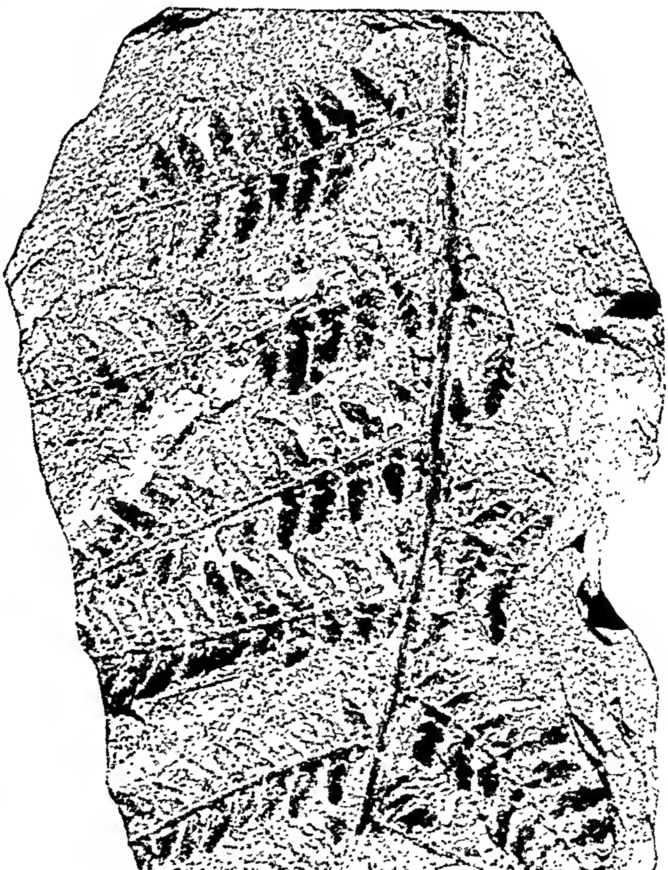


Fig. 11. A remarkably well preserved fossillised fern.

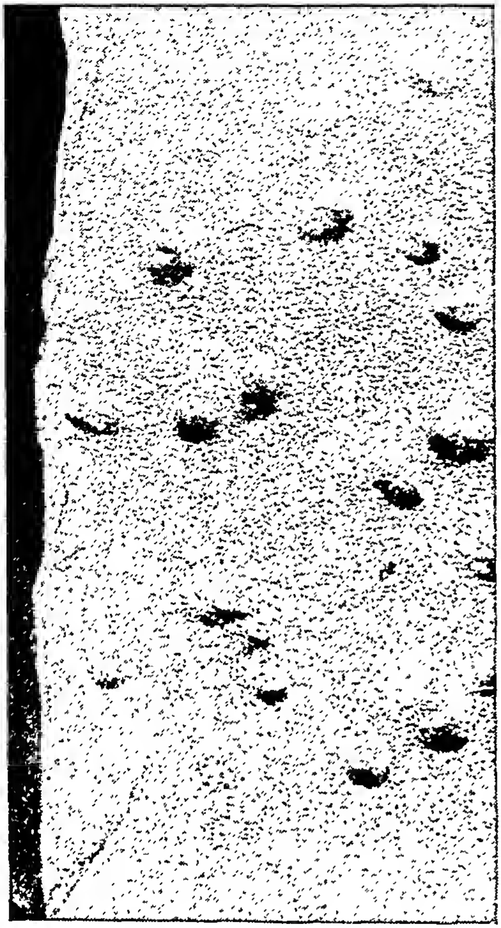


Fig. 12. Prehistoric raindrops. These fossilised impressions were found in sandstone rocks that formed part of the seashore millions of years ago and were later compressed.

Another reptile of a similar type was the Plesiosaurus, with the body and tail of a quadruped and a long neck, at the end of which was a small head. It was able to move quickly through the water by means of four large paddles, which in some cases have been found to be over 7 ft. in length. Fossils of Plesiosauri have been found at Ely, Peterborough, Whitby, and elsewhere. This creature is of special interest at the present time because it has been suggested that the far-famed "Loch Ness Monster" may be a living example of a Plesiosaurus, a surviving link with those prehistoric times. If this is the explanation of the mystery of Loch Ness, it is probable that there is more than one "monster" and that these creatures have managed to breed and survive in the 900-ft. deep Scottish loch, where subterranean caves deep down in the waters of the lock give access to the sea. Whatever the "monster" may be, it seems established that, if it exists at all, it is an amphibian—that is to say, it breathes air with lungs and can equally "breathe" water with gills. There is certainly some similarity between the prehistoric Plesiosaurus and the sketches, photographs, and descriptions given of the "Loch Ness Monster".

THE HUGE DINOSAUR

In later times new creatures appeared that lived entirely on the land. The Dinosaurus, for instance—half-whale, half-lizard and measuring up to 80 ft. in length. Large numbers of fossil dinosaurs have been discovered in Utah, U.S.A., in Tanganyika, and elsewhere. Another huge creature was the Diplodocus, examples of which have been found measuring up to 80 ft. in length. Then there was the terrible Allosaurus that resembled a giant kangaroo with crocodile's teeth, and a head as large as a horse. This ferocious creature, which walked on its hind legs, lived on the vegetable-eating Dinosaurs and probably exterminated them. One of the largest creatures that has inhabited the Earth was the Brontosaurus or Thunder Lizard. It measured over 90 ft. in length, stood 15 ft. in height, and weighed 40 or 50 tons. Another huge lizard was the Iguanodon, with bird-like feet, the thumb being in the form of a huge spur at right angles to the palm. Strange to say, these creatures had very small heads and their brains were no larger than a walnut.

All these creatures lived a very long

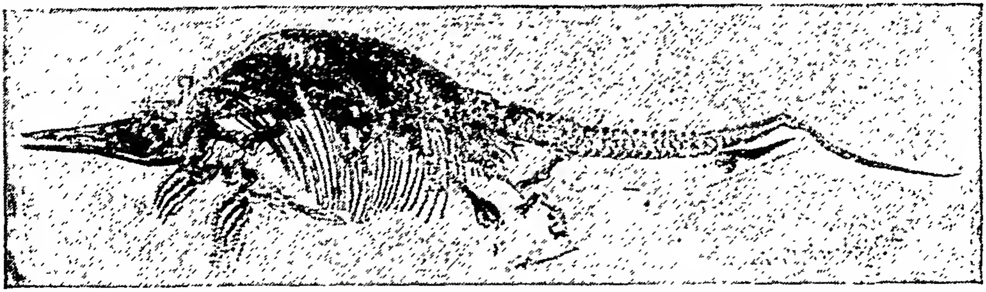


Fig. 13. A fossilised Ichthyosaurus, with embryo of young inside. This creature was a great fish-lizard, a long extinct marine reptile that measured 40 feet in length.

time ago—perhaps 120,000,000 years—and after inhabiting the Earth for, perhaps, 80,000,000 years they became extinct. They were followed by the mammals, which became dominant in a comparatively short space of time, and of these creatures we shall have more to say in a later section of this book.

Having learned something about the Earth's crust, let us now see what we know about what is beneath this outer covering. Naturally, we know more about what we can see on the surface than about what is hidden beneath. The deepest oil-drill ever made went 15,004 ft. down into the Earth, but even this is a mere pin-prick compared with the 4,000 miles to the Earth's centre. Even if we add the heights of the highest mountain ($5\frac{1}{2}$ miles) to the depth of the deepest ocean (about 6 miles) making, say, 12 miles, we get only a minute

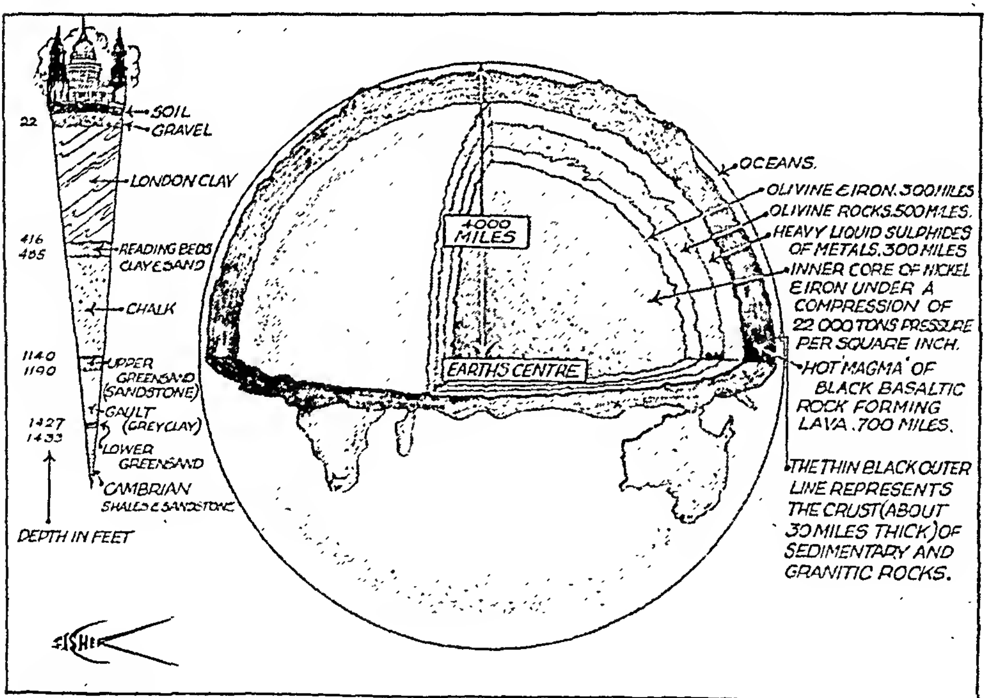


Fig. 14. What the inside of the Earth may look like, showing how relatively thin the crust is. On the left is a section of the crust under London.

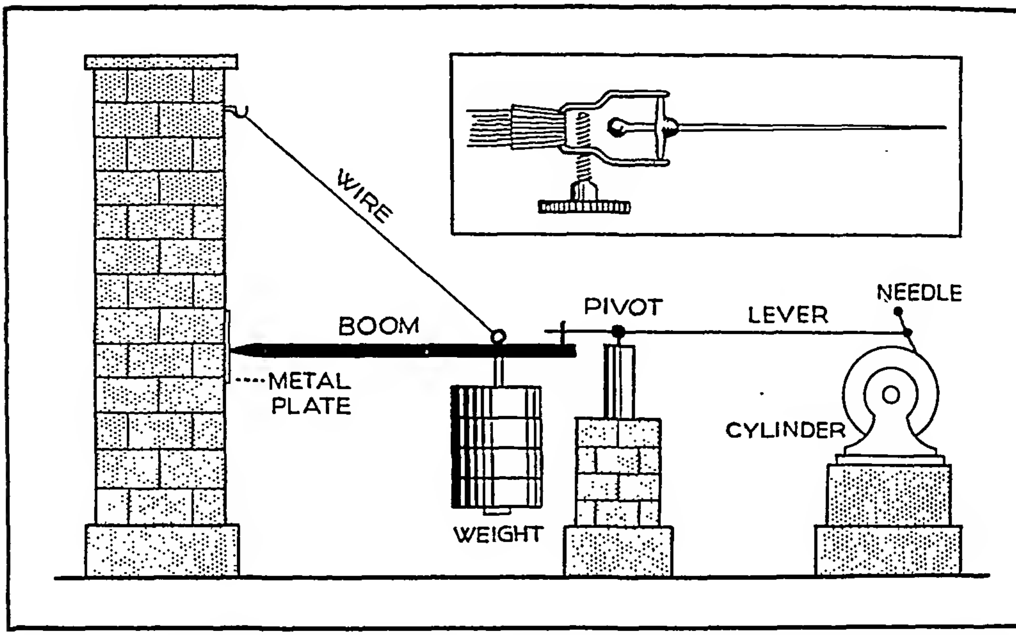


Fig. 15. How the Seismograph works. *Inset* shows how the fine glass needle is fixed to a light extension. This needle must be free to move vertically and to rest lightly against the smoked paper on the cylinder shown with the rest of the apparatus below.

fraction of the total radius of the Earth. It is clear, therefore, that we can learn little or nothing from actual observation of the conditions of the Earth's interior and that for our knowledge we must rely on other methods.

DENSITY OF THE EARTH'S CRUST

The average density of the rocks of the Earth's crust has been found to be from $2\frac{1}{2}$ to 3 times that of water. Similarly, careful measurement shows that the density of the Earth as a whole is about $5\frac{1}{2}$ times that of water. From this it follows that the density of the Earth must be considerably greater near its centre than near the surface. We are thus led to the conclusion that either the Earth's interior is under greater pressure than the surface, or that it has a larger proportion of denser substances than occurs at the surface.

Density increases with pressure, and as the pressure at a depth of 100 miles amounts to over 300 tons to the square inch, we might be justified in assuming that at great depths the enormous pressure is the cause of the increase in density. This theory, at one time held fairly generally, has now been discarded, however, in view of certain serious objections. Instead, it is generally believed that the high specific gravity of the Earth's interior is due to its being largely composed of heavy metals, probably iron or iron and nickel. Careful study of earthquake records leads us to believe that there is an outer crust perhaps 25 or 30 miles thick. Below this is a homogeneous, or uniform, layer that extends probably to a depth of 2,000 miles, with a central core that may be plastic or even liquid, but under enormous pressure, calculated to be equal to about 22,000 tons to the square inch (Fig. 14).

Earthquake records are obtained by an instrument known as a seismograph—a kind of pendulum to which a recording device is fixed. A simple seismograph

that will give interesting records can be made without difficulty (Fig. 15). A metal bar, perhaps 5 ft. in length, is hung by a wire against a wall running north and south, or east and west. The bar, or "boom", rests against a metal plate to prevent it digging into the wall. Towards the opposite end of the lever hangs a heavy weight that may be a number of bricks fastened together. At the end of the lever a light extension lever—such as a long wheat straw, or piece of fine aluminium tubing—is fixed on a pivot, engaging between two uprights on the main lever, its purpose being to magnify mechanically any slight movement of the weighted lever. The record is made by a stiff bristle, or fine drawn glass thread, fixed by a spot of shellac or seccotine to the extension lever, and resting on a smoked paper carried on a revolving cylinder.

The weight remains in a comparative state of rest forming a steady point, so that when the wall is moved by earth-waves, the movement is transmitted through the weighted lever and so through the magnifying lever. The movement causes the recording bristle to move to an extent many times greater than the original movement. It scratches on the smoked paper of the revolving cylinder a zig-zag line instead of the normal line that is given when there is no earth-movement. This record is called a seismogram.

THE SENSITIVE SEISMOGRAPH

There are several forms of seismographs, but all work on the same principle. One that is now generally used, the Milne-Shaw, depends on a horizontal pendulum—a rigid metal rod supported vertically on a masonry column (Fig. 16). The boom is an aluminium rod with an arrangement at the extremity for reflecting a beam of light through suitable lenses on to a drum carrying sensitized paper. An apparatus is incorporated for "damping"

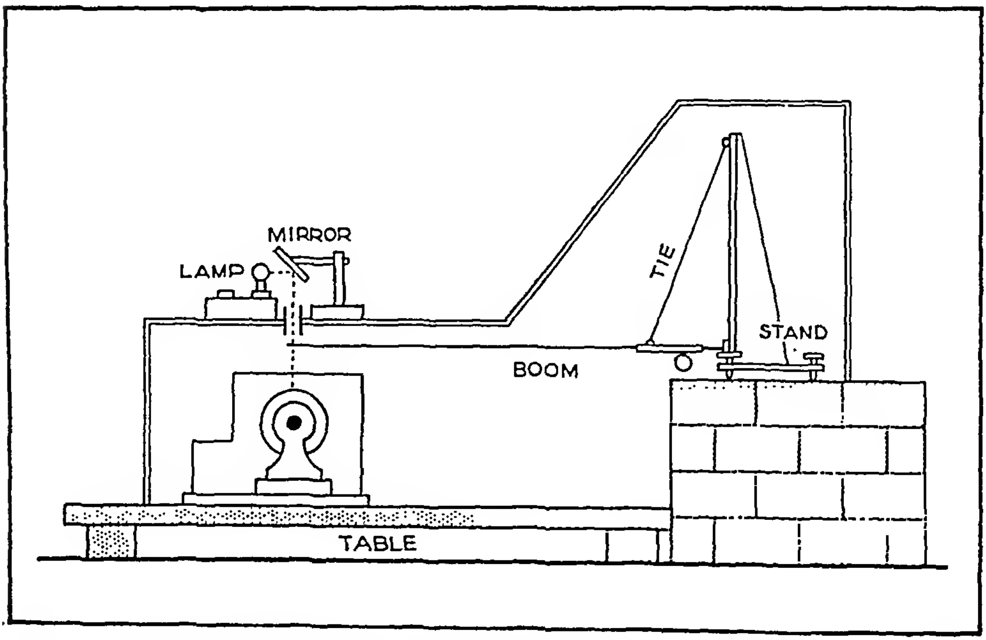


Fig. 16. The principle of the Milne-Shaw seismograph, showing how it is operated by a horizontal boom working from a fixed column. (For explanation of working, see text).

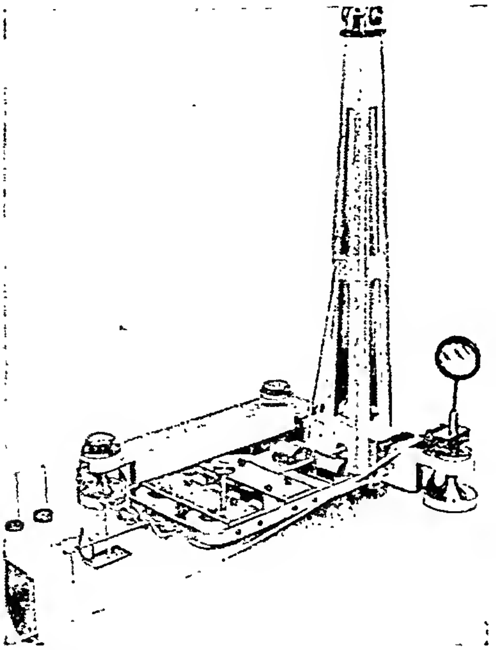


Fig. 17. The vertical pendulum of a Milne-Shaw seismograph for recording earth tremors by a light beam falling on sensitised paper.

the movements of the pendulum by magnets. It has the effect of bringing the boom quickly to rest after each oscillation. The vertical pendulum, boom, and damping magnets are shown in Fig. 17. Such a seismograph is so sensitive as to show that the building in which it is housed sways like a tree in the wind. It will also show that the coast-line is depressed for several miles inland with each rise in the tide. It shows, too, that a person standing on the ground makes a depression that extends for many feet around the spot.

Earthquakes may be caused by volcanic activity releasing molten matter, so causing a subsidence of the Earth's crust; or by "faulting"—the slipping of rocks below the Earth's surface. When an earthquake occurs at any place waves are generated in the Earth's crust, just as waves occur in a pond when a stone is thrown into it.

TYPES OF EARTH WAVES

Earth waves are of three types, two of which—the primary waves and the secondary waves—travel through the interior of the Earth, while those of the third type—resembling the surface-waves in the pond—travel on the surface (Fig. 18). All the waves originate at what is called the focus or seismic centre, and in due course they reach the recording stations where seismographs are installed. The vibrations of the primary waves are sent out in the direction of travel and these waves are therefore said to be of a

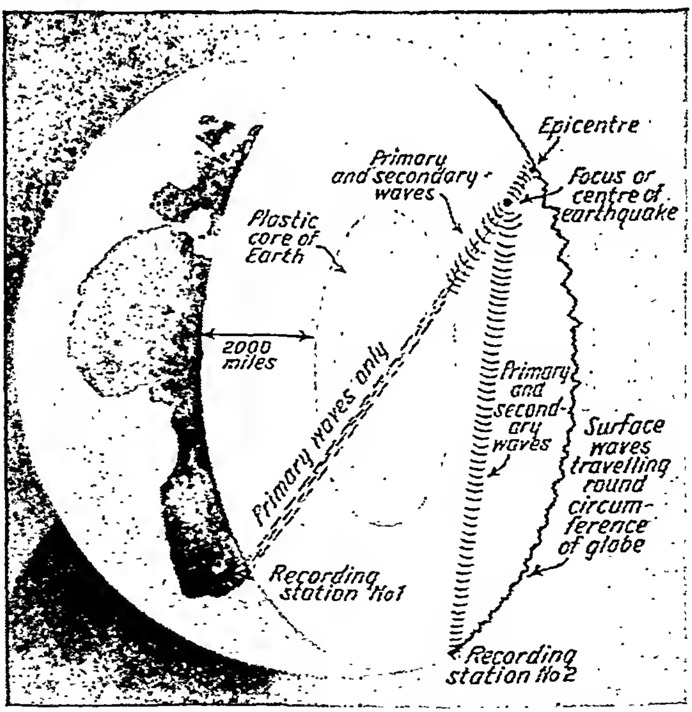


Fig. 18. The three different types of waves, propagated by an earthquake. Only the primary waves travel through the Earth's core whose extent can be measured by reason of this fact.

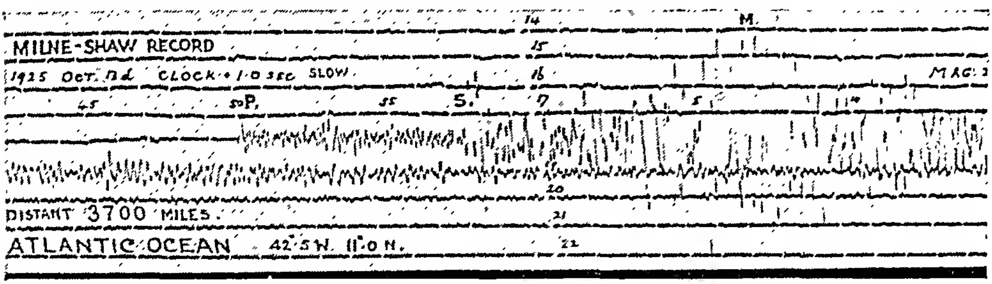


Fig. 19. Typical record showing Primary (P), Secondary (S) and Maximum (M) waves. The intervals between the arrival of each kind of wave shows the observer how far off is the disturbance. Readings from other stations can be used to locate its source.

longitudinal character. The secondary waves follow the same path as the primaries, but travel at a slower speed. As their vibrations are at right angles to the direction of travel they are known as transverse waves. As the time required for the primary and secondary waves to arrive varies according to the distance of the focus from the recording station it is possible to calculate the distance of the focus by noting the difference in the time of arrival of the two waves as recorded by the seismograph. Thus the observer can tell approximately where the earthquake is taking place. Two earthquake recordings on a Milne-Shaw seismograph are reproduced in Figs. 19 and 20.

Science has not succeeded in devising any method of accurately forecasting earthquakes, although evidence is accumulating that may lead to some such achievement. There are two kinds of evidence that may help in this matter. In the first place earthquakes have now been recorded for a great many years, and the statistics are carefully studied to see if the variation in their frequency is in any way related to other known terrestrial variations. The average total number of earthquakes is about 4,000 per annum, and although most of them are very feeble, one in every sixty is capable of being registered. Even in seismic countries like Italy or Japan only two earthquakes in twenty are destruc-

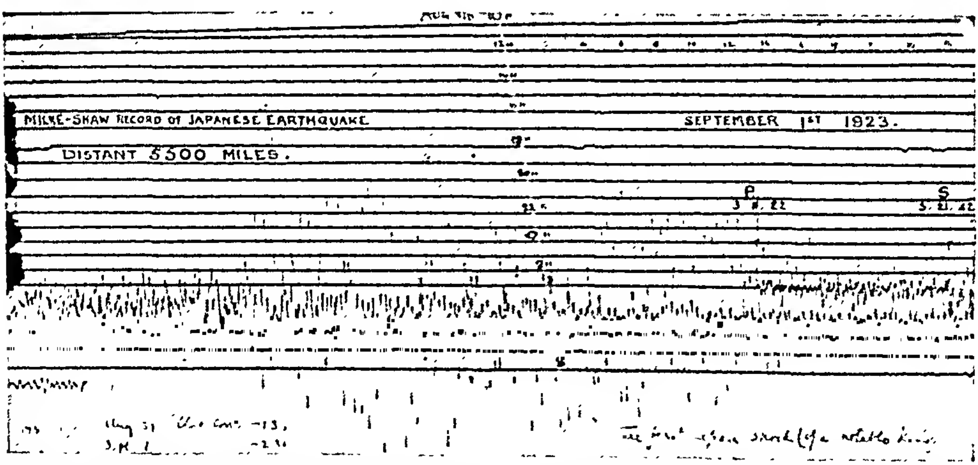
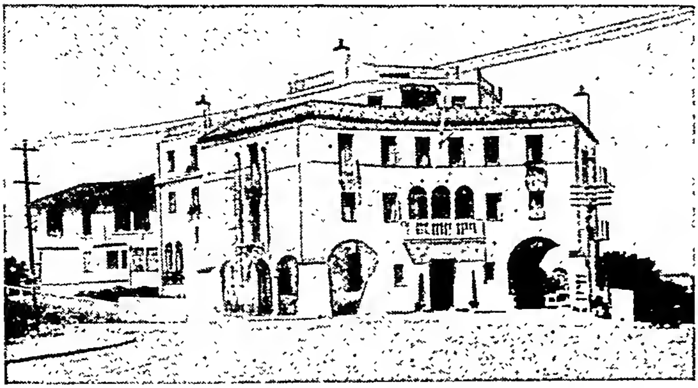
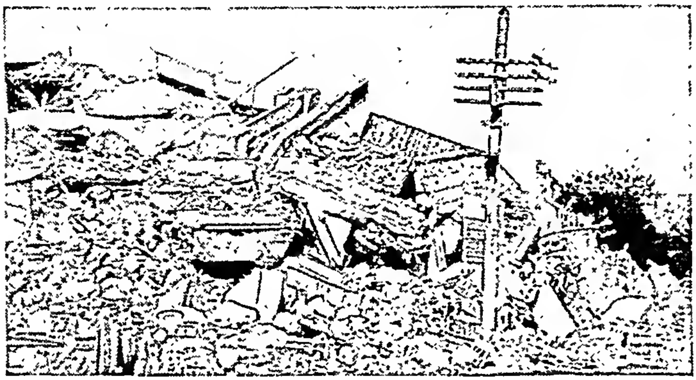


Fig. 20. The record in England of the great earthquake on 1st September, 1923, in Japan. This earthquake destroyed Tokio and Yokohama. The disturbance was 5,500 miles from the seismograph.





Figs. 21, 22. The Nurses' Home and offices at Napier Hospital, Hawkes Bay, N.Z. before (above Fig. 21) and after (below Fig. 22) the great earthquake of 1931. Note the telephone pole at right-hand corner of building (Fig. 21) was still standing.

tive. These destructive earthquakes tend to occur in groups that may be spread over some years, and records show that they are followed by a period of comparative quiet. Thus in Japan an average period of thirteen years occurs between epochs of destructive activity, and a similar kind of sequence has been noticed in other countries affected by the earthquake.

It is very difficult to explain these variations, however, and many other factors may enter into the matter. It is known, for example, that, on the average, earthquakes are more frequent in mid-winter and that they vary through the year in a way similar to the annual variation in barometric pressure. Again, a maximum frequency seems to coincide with periods when Sun, Moon, and Earth are in line. Another consideration to be taken into account is the position of the Earth's axis which, as we have seen, "wobbles" like a spinning top. It is improbable that any one of these details of the Earth's behaviour *produces* an earthquake by itself, but if any part of the Earth is in a strained condition, increased barometric pressure, greater gravitational pull by Sun and Moon, or a sudden "wobble" of the Earth may provide the "straw that breaks the camel's back".

An immediate and extremely important aid in forecasting earth-tremors lies in the observed fact that a major earthquake is preceded by a series of preliminary shocks.

Great damage and loss of life occurs when an earthquake takes place beneath a town or city. One of the most disastrous earthquakes of recent times was that of Hawkes Bay, New Zealand, on 3rd February, 1931. Within thirty seconds, and without the slightest warning, the busy town of Napier was in ruins and hundreds of people were killed. Fires broke out in various places simultaneously and could not be controlled owing to the absence of water and blocked streets (Fig. 21 and 22).

Much could be written of this and other disastrous earthquakes but limitations of space forbid. We are more concerned here with learning what the seismograph can tell us about the

Earth's interior. We find that when the distance between the origin of the earthquake and the recording station is so great that the path of waves extends to a depth of 2,000 miles, the secondary waves do not reach the recording station. This is accounted for by the fact that although the primary, or longitudinal, waves will pass through liquid or plastic material, the secondary, or transverse, waves cannot do so. Thus we infer that the interior of the Earth at a depth of about 2,000 miles must be in a liquid condition.

BENEATH THE EARTH'S SURFACE

Whatever may be the actual condition of the Earth's interior, its temperature must be comparatively high, although there is no actual evidence that it exceeds perhaps 5000° F., a temperature that we can command in the laboratory. We know that in penetrating the Earth's crust in mining, the temperature increases with the depth of the shaft, and in many of our deep coal mines it is too hot to be comfortable. The rise in temperature appears to vary according to the situation. By lowering special thermometers into a deep boring, made some years ago when searching for coal near Leipzig, it was found that there was an increase of 80° F. at a depth of a mile, the temperature rising at a uniform rate of 1° F. for each 66 ft. in depth.

In a boring in California, oil was struck at a depth of 7,591 ft.—the deepest producing-well ever drilled—and here the rise in temperature was at the rate of 1° F. for every 25·5 ft. of depth. In Wyoming U.S.A. the increase in temperature is 10° F. for every 22 ft.—a rise that is so rapid that the temperature at which water boils (212° F.) would be reached at a depth of only 350 ft. It is significant that the famous Yellowstone Park, with its many thermal springs and geysers, is situated in the

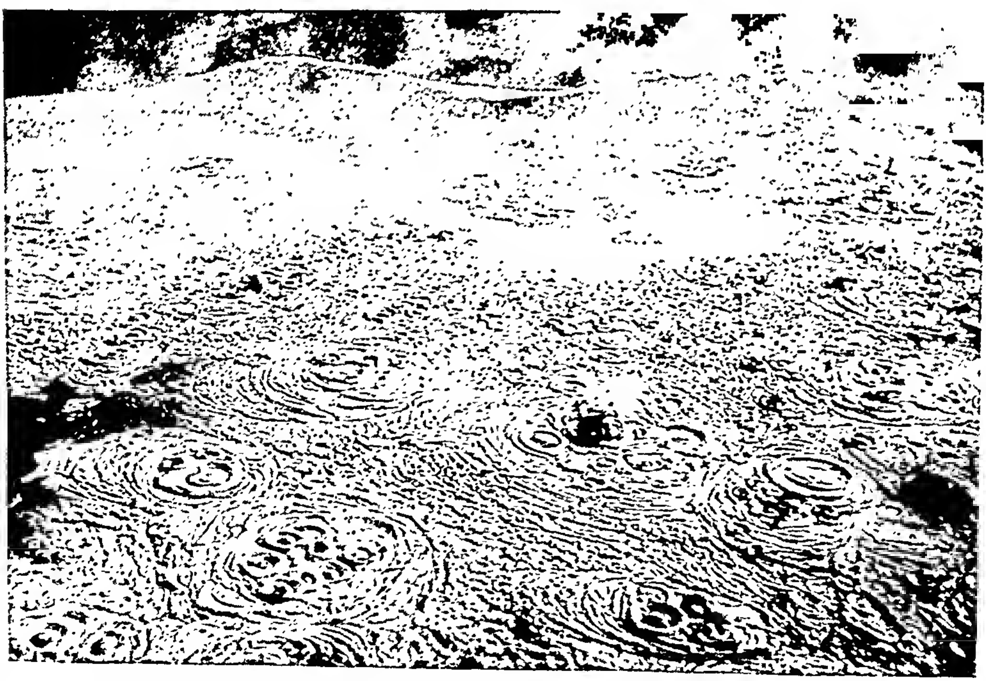


Fig. 23. Boiling mud in the crater of a mud volcano at Tiketere, New Zealand.

Fig. 24. The Pohutu Geyser at Whakarewarewa, in North Island, New Zealand. It is the largest in the world the water being ejected to a height of 500 to 1,500 feet at regular intervals, through a "pipe" 80 feet in length.

The chief difficulty in the way of carrying out such an enterprise would be to control the temperature, for, generally speaking, it may be said that water would boil at a depth of two miles and iron would melt at seven miles.

We can understand now whence the water spouted by hot springs and geysers gets its heat. In Yellowstone Park, which covers an area about as large as Yorkshire, there are over 3,000 hot springs, the water coming to the surface at varying temperatures. Hot springs are numerous, too, in Mexico, Iceland, Italy, New Zealand, and elsewhere—in fact in nearly all parts of the world where there are active volcanoes, or in regions where the mountains have been formed by volcanic activity. In New Zealand many of the thermal springs are filled with hot mud deposits. Known locally as the "Porridge Pots", the mud within may actually be seen to boil (Fig. 23). The Maoris use the hot springs for cooking their food.

Hot water is ejected through vents in the Earth's crust to form geysers as distinct from springs. The best known geysers are found in New Zealand, Yellowstone Park, and Iceland, where there are over a hundred in an area of two square miles. Most of these natural fountains have a regular intermittent

state of Wyoming where these high temperatures occur.

Sir Charles Parsons, the famous engineer who so successfully developed the steam turbine, suggested the sinking of a shaft to a depth of 12 miles at an estimated cost of £20,000,000. He believed that such a shaft would strike sufficient coal and oil to supply all requirements for millions of years, and would release untold wealth—radium, gold, silver, and diamonds, as well as new metals and fresh sources of energy.

activity. Water accumulating in a subterranean chamber in which the temperature is above boiling point, is converted into steam as in a boiler. When a further quantity of water is admitted to the chamber it is forced out through the vent in an eruptive fountain by the tremendous pressure of the steam. The process is repeated at intervals which depend on the length of time required to convert the next supply of water into steam.

WORLD'S LARGEST GEYSER

The largest geyser in the world is Pohutu at Whakarewarewa in North Island, New Zealand (Fig. 24). It has a "pipe" 80 ft. in length and ejects a column of water to a height of from 500 ft. to 1,500 ft. In the Wairakei Valley is the Champagne Cauldron, spouting columns of effervescing water into the air every few minutes. Here, too, is the Great Geyser that spouts to a height of 30 ft. every ten minutes. The Crow's Nest similarly shoots boiling water to a height of 40 ft. every half hour.

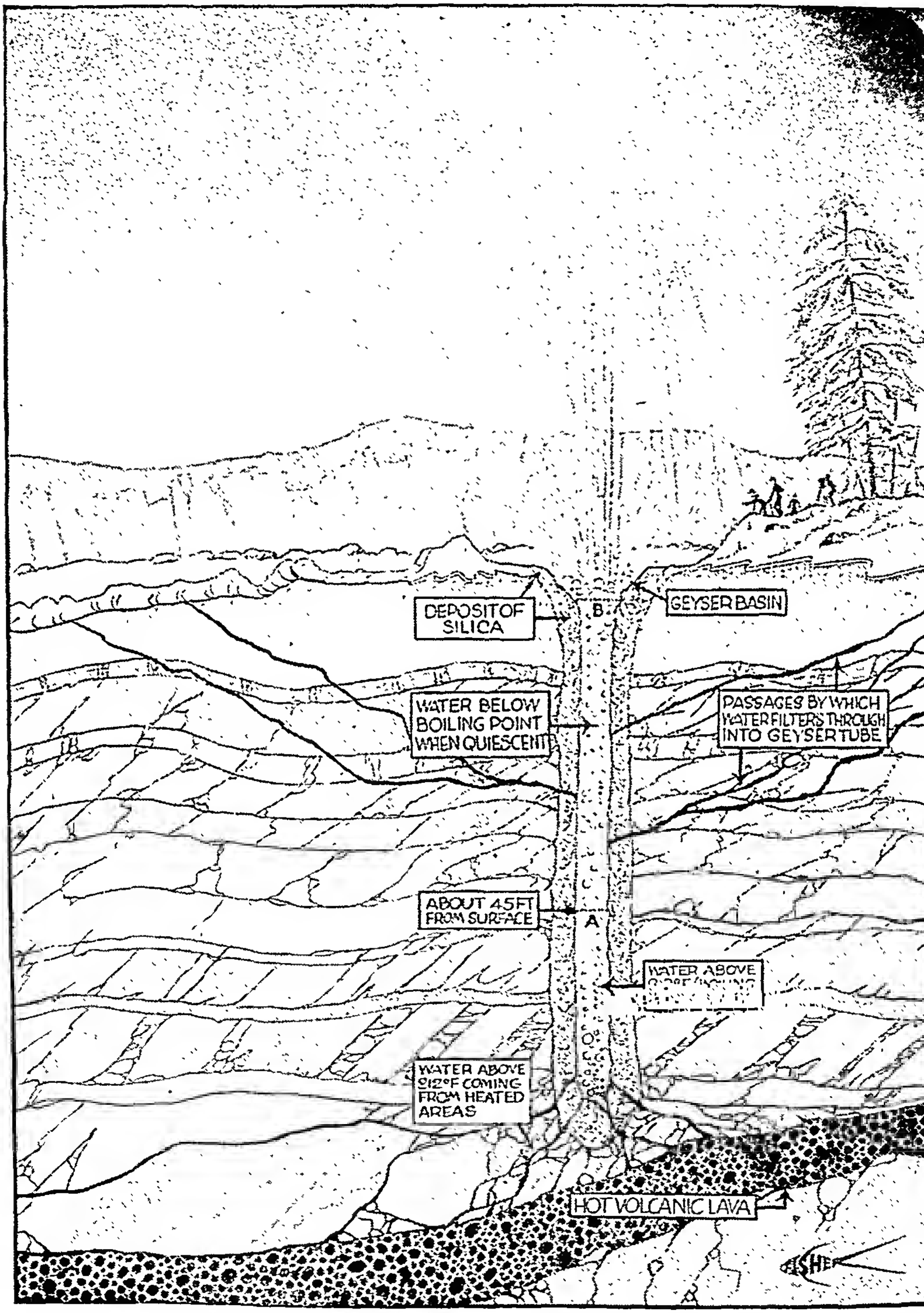
There are over a hundred active geysers in the Yellowstone Park, U.S.A., including the Giantess that "obliges" at intervals of 10–20 days, spouting to a height of 200 ft. for a period lasting from 12 to 36 hours. Here, too, is the most famous geyser in the world, "Old Faithful", so called because of the regularity of its performances (illustration on p. 114). For the past thirty years it has regularly spouted for four minutes at a time a column of boiling water and steam to a height of about 150 ft. every 60 to 80 minutes. At each "spout" over 1,500,000 gallons of water are ejected, equalling over 33,000,000 gallons every day.

This intermittent type of geyser is believed to owe its activity to the sudden generation of steam, caused by the general rise in temperature of the water in the pipe. As we have already seen, the boiling point of water at sea level is 212° F., but this boiling point rises with depth. Referring to Fig. 25, we see that the geyser tube is filled with water that percolates into it from fissures. Hot water also enters the tube A from below, its temperature being considerably above boiling point from its contact with the heated lava and rocks deep down below the crust. This water at A cannot generate steam because of its great pressure and because of the cooler water at B in the column above. The hot water rises and reaches a point (about 45 ft. below the surface) where steam can be generated by the decreased pressure. Steam under pressure has tremendous energy—steam heated to 100° C. requires 1,650 times the space of water at the same temperature—and the sudden conversion of water into steam blows the 45-ft. column of water high into the air. It falls in the basin and the column fills again, to repeat the process with clockwork regularity, while the conditions remain the same.

WHAT IS A VOLCANO?

Volcanoes are similar to geysers in their action, except that they eject lava or molten rock, ashes and steam in great quantities instead of water. They are openings in the Earth's crust that act as safety valves for the forces below, releasing them in a measure when they become too great for the Earth's crust to withstand them. The volcanic matter is ejected through a pipe-like passage, called the vent, around which the material falls as water falls around the jet of a fountain. This ejected material forms a cone, the top part of which—generally basin-shaped—is called the crater (Fig. 26).

There are about 1,000 volcanoes in all, of which about 350 are on the



HOW A GEYSER WORKS.

Fig. 25. Sectional details showing the working of "Old Faithful" geyser in Yellowstone Park. *A picture of the geyser, probably the most famous in the world, in full action is seen on page 114, and an account of its workings is given on page 131.*

"active list". Fortunately there are no active volcanoes in Britain, although it is clear that at one time in the Earth's history such did exist. North Berwick Law, Edinburgh Castle Rock, and Loudoun Hill, Ayr, are the funnels of extinct volcanoes. Around the Firth of Forth, on the Isle of Arran, and elsewhere in Scotland, there are extinct volcanoes of considerable magnitude. Castle Head on Derwentwater, and the picturesque Friars Crag at Keswick are the stumps of extinct volcanoes. In Shropshire, in the Isle of Man, and in North Wales also may be seen the results of intense volcanic activity. A truly remarkable volcanic relic is the hill on which is perched the chapel of St. Michel at Le Puy in France. The hill is the pipe of an extinct volcano, the lava having solidified in the pipe (Fig. 27).

Certainly the best known European volcano is Vesuvius, overlooking the Bay of Naples in Italy. Fig. 28 shows its probable interior arrangement. Before the eruption of 1906 the mountain was 4,200 ft. in height, but now it is 3,660 ft. The present cone stands a little to the south of the centre of the older crater, which is a walled plain a mile or more in circumference. It was by this volcano that (in A.D. 79) Pompeii was buried beneath a torrent of volcanic ash, and two other cities, Herculaneum and Stabiae, were destroyed, over 200,000 people losing their lives. Then for nearly 1,500 years Vesuvius was quiet, until in 1631 there was another eruption. Streams of lava flowed down the mountain, and clouds of dust ejected from the crater were carried as far as Constantinople. Great streams of mud reached to the Apennines and 18,000 people were killed. Since that time the volcano has been more or less active at varying intervals—in 1906 two villages were overwhelmed by ashes; at Naples the ashes were 3 ft. in depth.

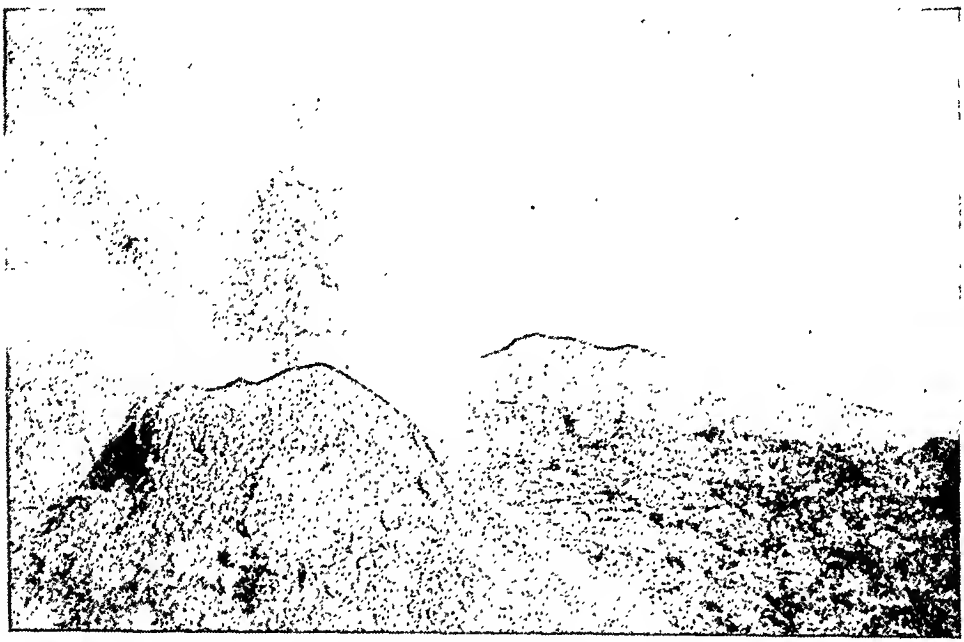


Fig. 26. The great volcano Vesuvius on the Bay of Naples, showing smoke escaping from the present cone. Surrounding it and in the background are the walls of the crater.

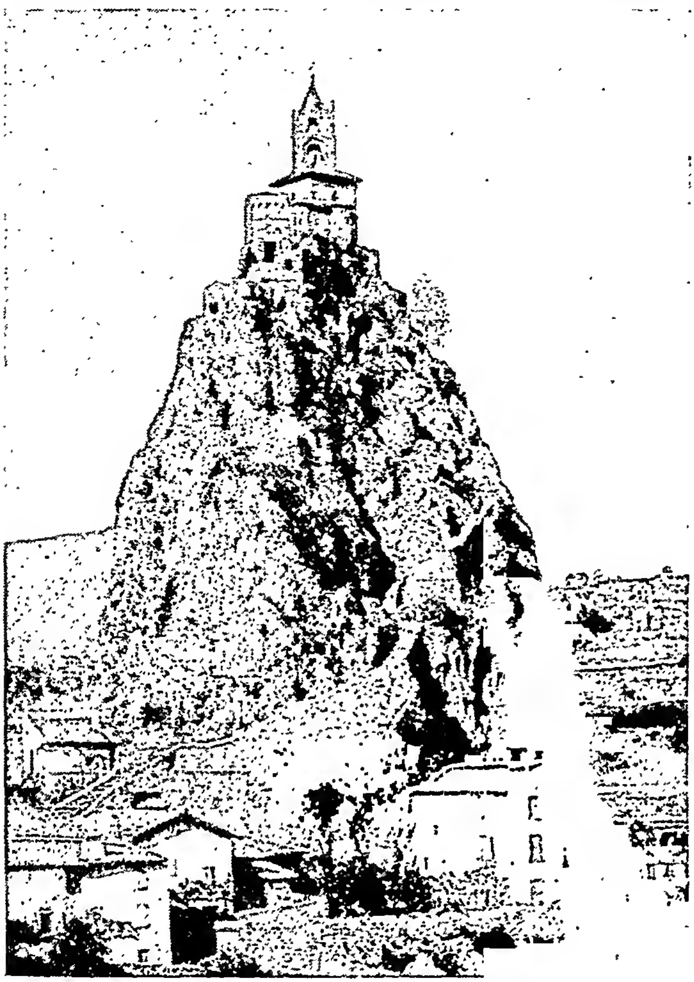
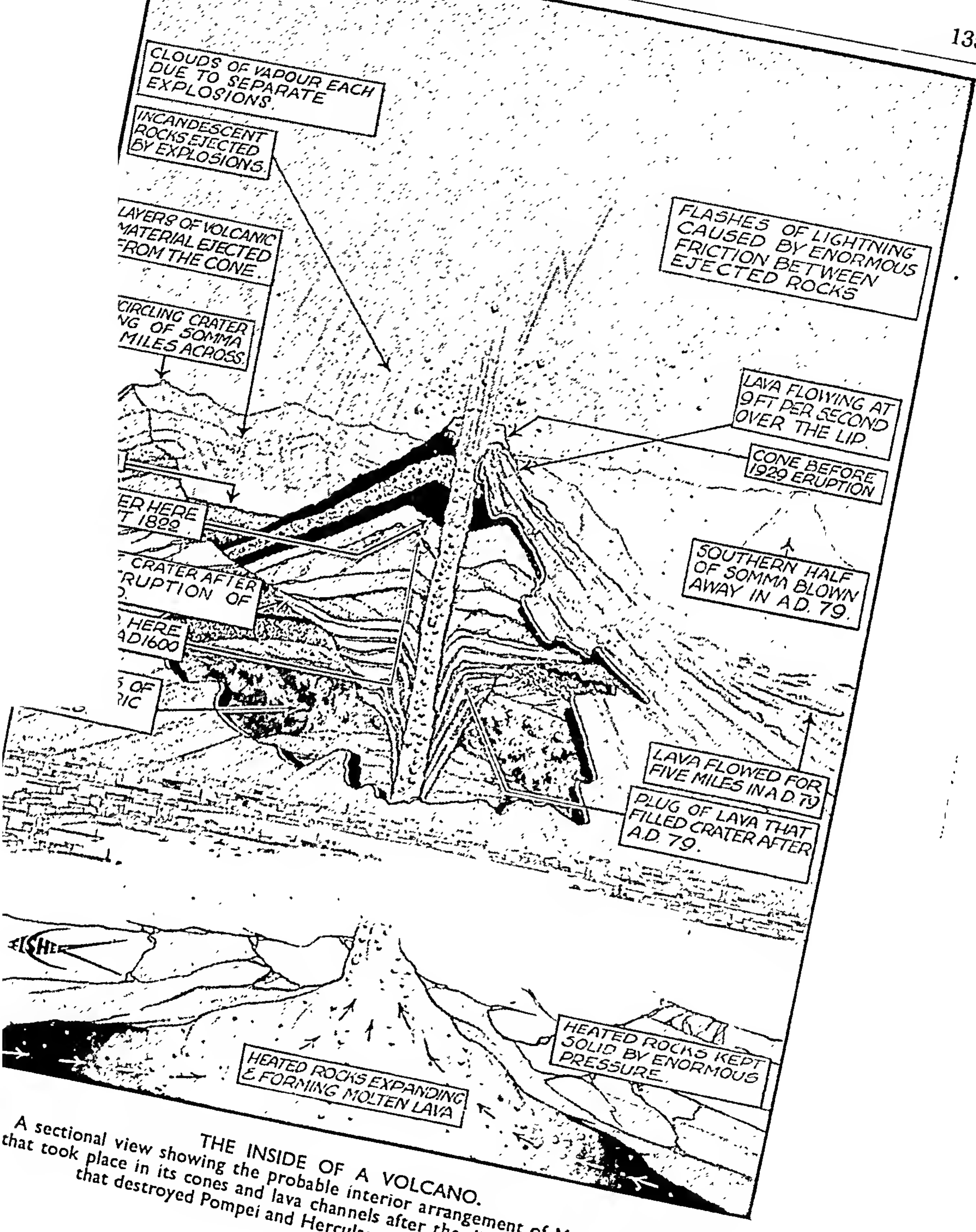


Fig. 27. St. Michel's Chapel at Le Puy, Haute Loire, France. This peculiar hill was once the "pipe" of a volcano. The softer rocks have all worn away, leaving only the hard core.

Limitations of space prevent us from referring to more than a few of the eruptions which have shown how violent are the forces of the Earth's interior. Mention must be made, however, of the world's greatest explosion, the one that occurred on the island of Krakatoa in the Straits of Sunda near Sumatra in 1883. On the island was—and is—a volcano which at that date was considered to be extinct; but in the spring of the year there were deep rumblings and earthquakes that heralded the cataclysm. Every day the noises increased until they could be heard at a distance of 20 miles. A dark cloud of dust hung over the island, causing day to be as dark as night for hundreds of miles around. The water around the island became so hot that shoals of fish were killed. By the middle of August the darkness had become general over the Strait and neighbouring coasts and there were repeated earthquakes. There were terrifying sounds similar to artillery fire, accompanied by crackling noises caused by the impact of fragments of rock as they were hurled up out of the volcano.

On 27th August there were two or three explosions, and these were followed by a frightful convulsion that tore away two-thirds of the island and hurled a cubic mile of material high into the air. Enormous quantities of pumice and ash were scattered over a wide area, being in many places so thick that vessels could not move through the seas in which the material was afloat. So extensive was this distribution of ejected material that ashes fell on a ship 1,600 miles from Krakatoa. Great waves were caused in the sea, one of which reached over 50 ft. in height on the neighbouring coasts. It travelled over half the globe and actually reached the coasts of England and France. The devastating wave caused great destruction of life and property in the area around



THE INSIDE OF A VOLCANO.

A sectional view showing the probable interior arrangement of Mount Vesuvius. The changes that took place in its cones and lava channels after the disastrous earthquake of A.D. 79 that destroyed Pompei and Herculaneum, can clearly be seen.

Fig. 29. Krakatoa Island in Sunda Strait off Sumatra ; the scene of the world's greatest explosion in 1883 when two-thirds of the island were hurled into the air. Krakatoa is still active.

explosion, and the waters of the ocean, gaining free access, met the molten material rising from below. The immediate conversion of the water into steam resulted in what was virtually a gigantic "boiler explosion".

We have described already how rocks are formed. Let us for a moment learn something of the way in which they are destroyed. In an earlier section we mentioned that although the granite rocks were formed deep down in the Earth, granite may be seen on Dartmoor owing to earth-movements on the one hand and the removal of overlying rocks on the other. Exactly as the formation of new rocks is going on to-day, so too is denudation, for Nature

Krakatoa, and swept away all lighthouses and familiar landmarks along the coasts. Nearly 300 villages were destroyed and over 36,000 people perished.

The eruption at Krakatoa—where the volcano is still active (Fig. 29)—was undoubtedly the most severe explosion of modern times. It was probably caused by water from the ocean finding its way into the interior of the Earth, through fissures opened up by the preliminary earthquakes. The centre of the island collapsed in a preliminary

Fig. 30. How the weather wears away rock. This wall has only been in position about a century.

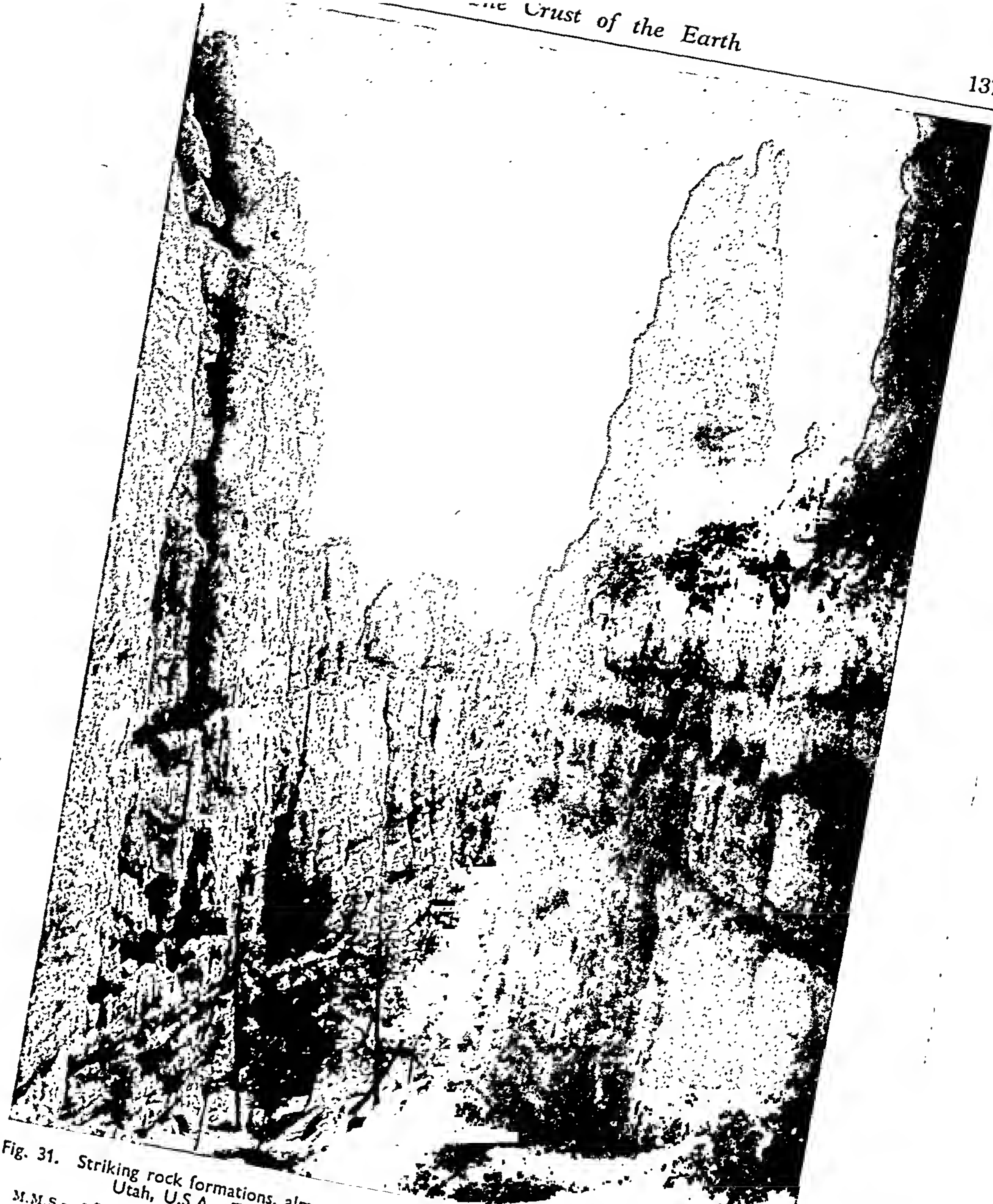
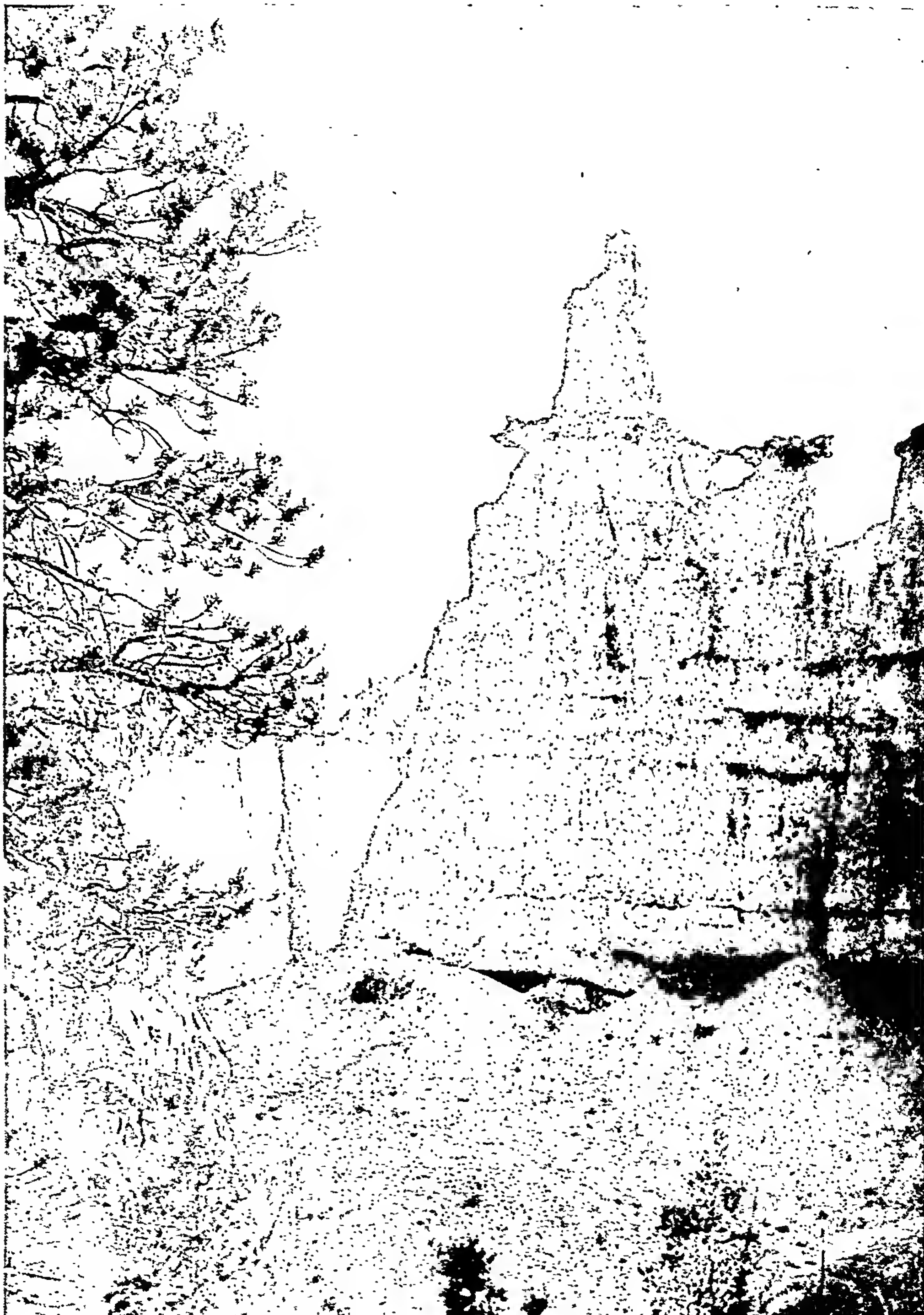


Fig. 31. Striking rock formations, almost skyscrapers in stone, in Bryce Canyon, National Park, Utah, U.S.A. These formations have all been produced by erosion.



NATURE MAKES A STATUE OF QUEEN VICTORIA.

Fig. 32. This wonderful rock formation in Bryce Canyon bears a remarkable likeness to Queen Victoria. It is purely the result of weather erosion and is untouched by hand.

is constantly at work creating and destroying, in a ceaseless cycle.

The chief agents by which denudation is carried out are frost, wind, and rain. Although to us these forces may appear to work very slowly, yet nevertheless they work with extreme sureness. There is no hurry, and the process may go on for a thousand or a million years until, in the end, the work of destruction is completed. Even in the short span of our own time we can see the effect of some of the forces of denudation in the "weathering" of the stones in old buildings or in old walls, particularly when these are composed of the less hard stones, such as various sandstones (Fig. 30).

EFFECTS OF FROST

We know that when water freezes it expands, for this is the cause of burst water pipes. The expansive power of water is very great, as may be shown by placing an iron cylinder filled with water in a freezing mixture, for when the water freezes it will burst the cylinder. Similarly, when the water in the fissures of a rock freezes at night, the rock may be rent asunder. In the course of time even the hardest rocks will be broken up by the drastic action of frost.

Further destruction is caused by the changes of temperature as between day and night. The heat of the Sun's rays during the day causes the rocks to expand, but when night comes and the temperature falls they contract, but at a much greater rate than that at which they expanded. The result of this continual expansion and contraction is that the rocks are split and disintegrated. Some rocks are broken up in this way more easily than others: for instance, granite, because it is composed of three materials that expand at different rates. Sulphurous and other acids, and carbon dioxide, are the chief agents here, and against them even granite and the hard crystalline rocks cannot stand up.

Wind-carried sand also takes part in the work, the sharp grains beating against the rocks and wearing them away. Notice a glass bottle on the sea shore, how it is etched until it looks like ground glass as the sand sweeps against it. Sometimes these wind-worn rocks present a remarkable appearance, due to some parts being harder than others and so resisting the destructive action for a longer time. In the great deserts of South California are some remarkable examples of this action, where ages of exposure have brought about the most fantastic shapes. In Red Rock Canyon, in the Sierra Nevada Mountains, is a great gorge in which the rocks have been carved by Nature into wonderful likenesses of buildings and animals. Pillars and fluted columns; pilasters and colonades; temples and castles; cathedrals, towers and domes, rise tier after tier and mile after mile. In Bryce Canyon, Utah, are skyscrapers (Fig. 31), and even in one place a gigantic natural statue of Queen Victoria (Fig. 32).

WIND-WORN ROCKS

In this country there are some excellent examples of wind-worn rocks at Brimham, not far from Harrogate in Yorkshire (Figs. 33 and 34). Here there are likenesses of monkeys, dancing bears and other animals. Sometimes these rocks rest only on a tiny support (Figs. 35 and 36) and are poised so delicately that a slight push is sufficient to set a 60-ton mass rocking. The Cheeswring on Bodmin Moor and the Logan Rock, near Land's End, are good examples of these "Rocking Stones", the largest of which—that at Tandil in the Argentine—weighs over 700 tons.

Another important agent in the work of denudation is rain. It is active largely because it has a chemical action

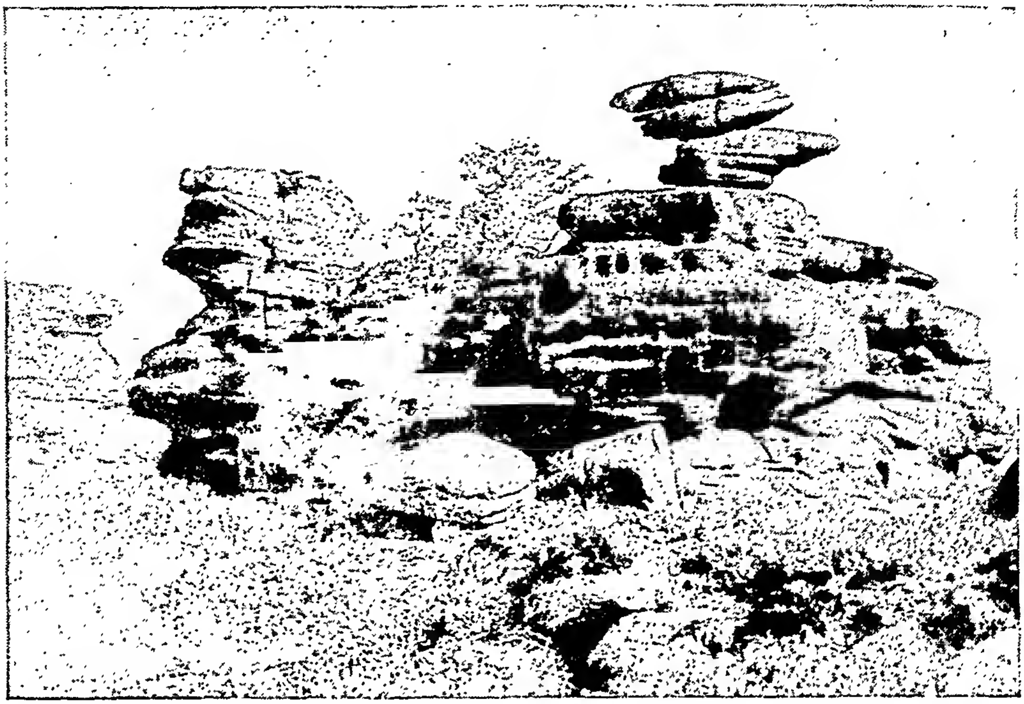


Fig. 33. Curiously worn rocks at Brimham, Yorkshire. The weather has eroded the overlying strata; and sand, carried by the wind, has worn the rock into fantastic shapes. Here and hereabouts are many startling likenesses of monkeys and other animals, worked and chiselled by those slow but tireless sculptors, the wind and the rain.

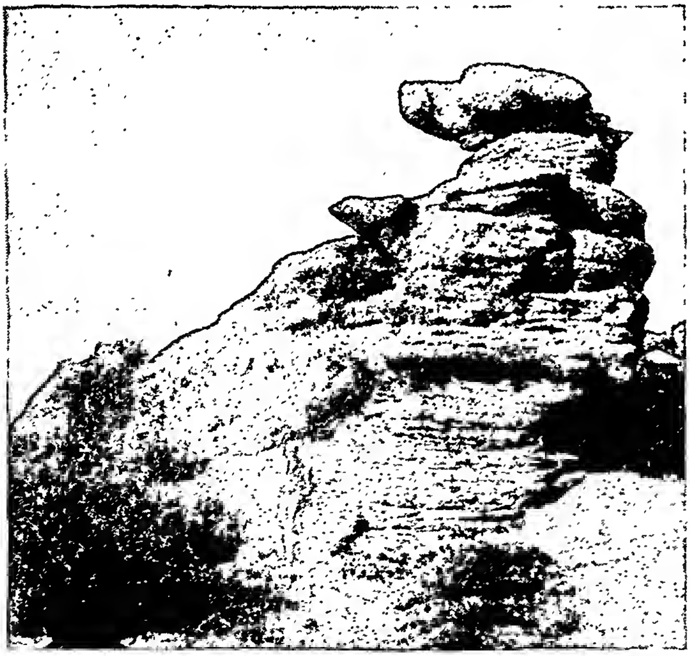


Fig. 34. More rocks at Brimham. This well-known formation has a curious but striking resemblance to a dancing bear.

brought about by the presence of the gases that it takes up from the atmosphere. These gases are chiefly oxygen and carbon dioxide, the former of which brings about the chemical changes, known as oxidation, that indirectly cause the rocks to decompose. At a temperature of 60° F. water will absorb its own volume of carbon dioxide and under normal conditions of temperature and pressure, 100 volumes of water will absorb 1·48 volumes of nitrogen, 2·99 of oxygen, and 100·2 of carbon dioxide.

We see the destructive effect of rain more particularly in our towns and cities, where the rain is heavily charged with impurities. In one city, for instance, a marble monument was found to have lost one-third of an inch over its surface in a century.

HOW RAIN ATTACKS THE ROCKS

Rain also penetrates through the cracks in the rocks caused by the changes of temperature and by frost, and so speeds up the general work of destruction. An enormous, but incalculable, amount of rain water percolates through the surface of the Earth and will disintegrate rocks at depths of 200ft. or more.

In Saxony (Germany) there is a mine 1,600 ft. in depth to which water percolates and drops from the roof. All through the intervening space from the surface of the land the constant "drip" does its deadly work, illustrating the truth of the old saying that "constant dripping will in time wear away the hardest stone".

If we assume—as we may reasonably do—that one third of the rain that falls on the land is quickly evaporated, the remaining two thirds, whether flowing into rivers or sinking into the ground, are at Nature's disposal for the purposes of denudation, either by chemical or mechanical means.

Where the rock formation is suitable, this percolating water, in its work of subterranean destruction, often forms caves. The carbon dioxide in the water converts insoluble carbonates into soluble compounds, giving rise to a solution of calcium carbonate. The amount of calcium carbonate thus dissolved out of chalk and limestone formations is very great, resulting in large and small caves being formed in the solid rock.

Some of these caves thus formed are of considerable size. The Postumia

Fig. 35. The Idol Rock at Brimham. This weighs hundreds of tons and rests on a tiny pinnacle (clearly shown above). Its great size can be gauged from the child beside it.

Fig. 36. The Cheeswring on Bodmin Moor in Cornwall, another amazing example of denudation. The other rocks and soil have been worn away, leaving the mass standing on two slender pinnacles.

in width, 125 ft. in height and some 4 miles in length. There are about 150 miles of passages—most of which are inaccessible—and mighty cataracts of falling water 250 ft. in height, lofty domes 300 ft. in height, and deep pits up to 200 ft. in depth.

In this country the Peak Cavern in Derbyshire is a well-known cave, as is Wookey Hole, near the Mendips, in which there is a subterranean lake (Fig. 37). In Yorkshire are innumerable caves and "pot holes" in the limestone region about Ingleborough. At one of the best known, Gaping Ghyll, a large pipe extends to a depth of 210 ft. and opens into the vault of an immense subterranean hall, 480 ft. in length, 110 ft. in width, and 100 ft. in height. Here the water has excavated a reservoir of 100,000 cubic yards capacity as well as about half a mile of galleries. Another pot-hole, Rowton Pot in Kingsdale, descends to 365 ft.

Although many such caves are known and have been thoroughly explored, there must be innumerable caverns and passages that have never been discovered, for everywhere the percolating water is at work, disintegrating the rocks and denuding the land.

In most of these caves stalactites are to be seen (Fig. 38). These beautiful objects consist of a semi-crystalline

(formerly the Adelsberg) Cavern, in the province of Trieste (Italy), and about 50 miles from the city of that name, has a succession of caves and connecting passages extending over a distance of 14 miles, and through some of them the River Piuca, formerly the Poik, flows.

MAMMOTH CAVE, KENTUCKY

The largest cavern measures 665 ft. by 640 ft. and is 100 ft. in height. The largest cave in the world is the Mammoth Cave, Kentucky, U.S.A., the main cavern of which measures up to 300 ft.

ENGLAND'S MOST FAMOUS CAVE.

key Hole, the great cave in the Mendips. The river flows through the Hole into
is point. This cave has been famous since 1874 when great discoveries of prehistoric
ins were made in the Hyena Den, a rock shelter in the Cheddar Gorge.

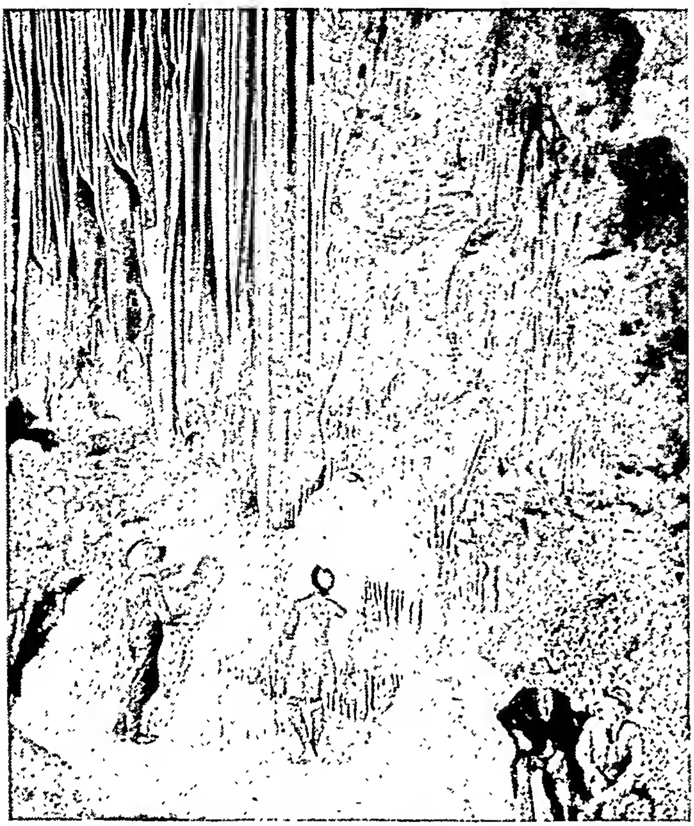


Fig. 38. The "Frozen Curtains," a number of very wonderful stalactite formations in the Big Room of the Carlsbad Caverns, United States of America. Stalactites always hang downwards.

process continues long enough, the two deposits meet, and joining together form a continuous column right from the floor to the roof of the cavern (Fig. 40).

Although the action of denudation by one agent or another is destroying the rocks, it also benefits the Earth in another way, for it is from this action that the soil is formed. The small pieces into which the rocks are broken up are spread over the land, and decaying vegetable matter sets free carbon dioxide, which, in solution, attacks minerals and supplies the soil with most essential organic matter. Living creatures, particularly earthworms and bacteria, help to convert the mineral matter into forms that are useful to plants, and it is from these sources that the soil gets the greater part of its so-called "goodness".

deposit, and are usually of a conical or cylindrical form. They form by water percolating through the rock and becoming charged with carbonate of lime. This is held in solution by the free carbon dioxide gathered by the water from the air and soil. When the water reaches the roof of a cavern from which it drips, the gas escapes leaving behind it the deposit of carbonate of lime in the form of an icicle-like pendant hanging from the roof. This explains why stalactites must always hang downwards. Sometimes an excess of water drips off the end of the stalactite on to the floor of the cavern, in which case the pendant form is reversed, and an upward-pointing pinnacle is formed. This is called a stalagmite (Fig. 39). Sometimes if the

Fig. 39. A typical stalagmite—the "Wedding Cake"—in the Ruakuri cave, New Zealand

Fig. 40. Huge pillars in the Carlsbad Caverns which must have taken countless ages to fo

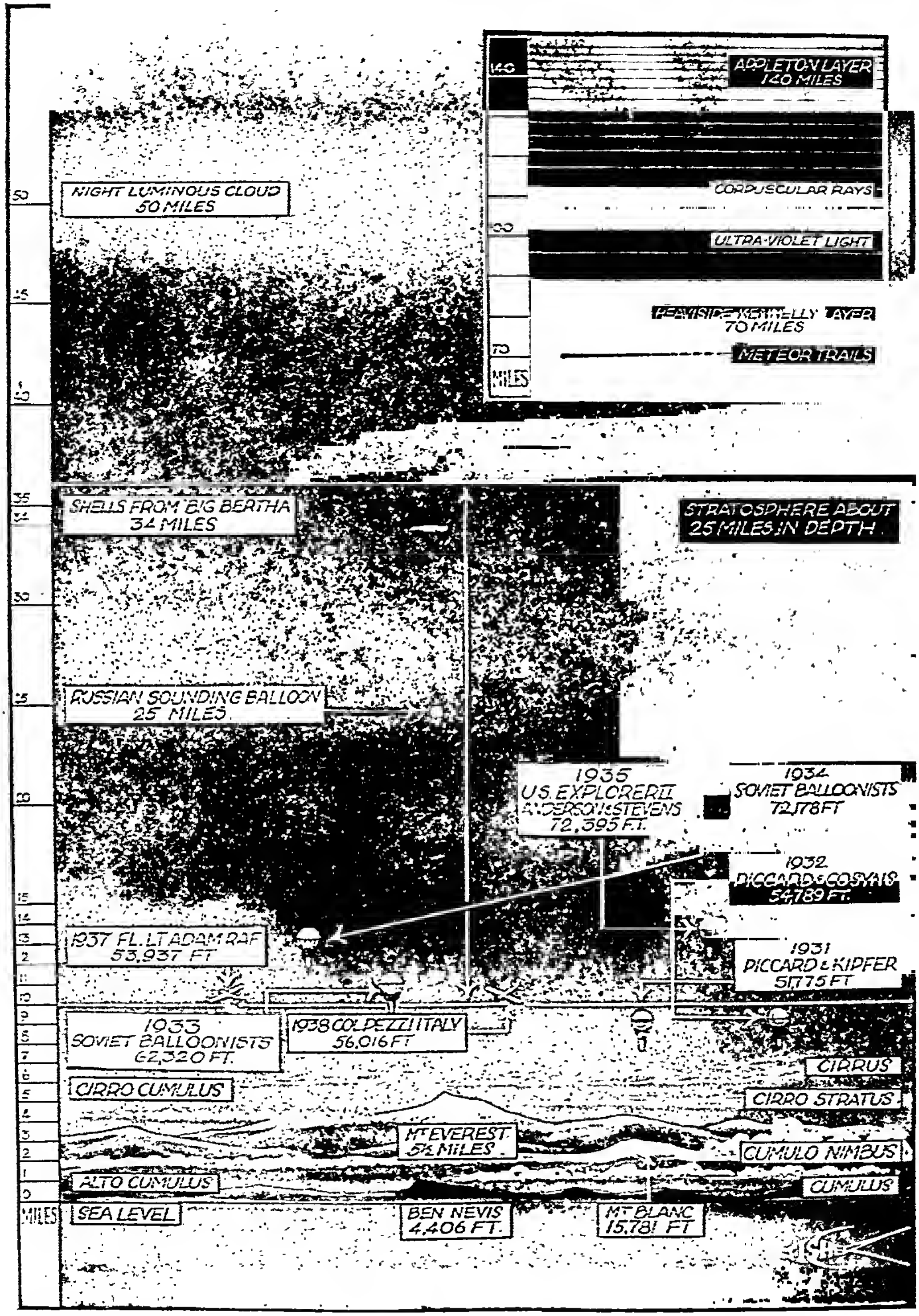


Fig. 1. The atmosphere above the Earth extends to about 200 miles, becoming more and more rarefied. Men have ascended in balloons to a height of between 13 and 14 miles. Unmanned balloons have attained an altitude of about 25 miles. Inset, the upper reaches of the atmosphere.

CHAPTER 9

THE ATMOSPHERE

THE atmosphere, or gaseous envelope that surrounds the Earth, acts as a kind of blanket, helping to keep in the heat and keep out the cold. It turns with the Earth as it rotates on its axis. If it were not for the atmosphere there could be no gradual dawn nor twilight, and we should be plunged into immediate daylight at sunrise and into darkness at sunset. As it is, the upper layers of the atmosphere catch the light of the Sun before it is above the horizon, bending and diffusing the rays so that they enter the lower atmosphere and give us the "half-light" of dawn. In the evening the rays from the setting Sun strike the upper atmosphere long after the Sun itself has sunk below the horizon, so that we have twilight. On the Moon, where there is no atmosphere, sunrise is immediate, and the darkness of the long lunar night is ended instantly.

No one knows to what height the atmosphere actually extends, but it is well known that it rapidly becomes thinner as the height increases. At a height of about five miles above the poles, and ten miles above the equator is the stratosphere. This is a belt of air, some 25 miles deep, that forms an upper layer of the atmosphere. It was discovered in 1897 by L. P. Teisserenc de Bort, a French meteorologist, when he sent up small balloons that carried automatically-operated registering instruments. The records obtained by these means suggested that the stratosphere was a region of constant temperature—about $-55°$ C.—although further investigations indicate that there is a slight variation within narrow limits.

Balloons and aeroplanes have taught us a great deal about the upper atmosphere and about the stratosphere. The first balloon was sent up in 1783 by the brothers Montgolfier in France, and many ascents were made subsequently. In 1862, two men, Glaisher and Coxwell, claimed to have reached what was then the record height of 37,000 ft.—about 7 miles. They nearly lost their lives in the achievement, the air being so rarefied that Glaisher became unconscious at 29,000 ft. In 1901, Dr. A. Berson and R. J. Suring reached a height of at least 34,500 ft., and in 1931 Professor Auguste Piccard and Dr. Kipfer, sealed in a spherical aluminium gondola and carrying liquid oxygen, rose to 51,775 ft. (about $9\frac{3}{4}$ miles). In the following year Piccard and Cosyns, in a similar balloon, reached 54,789 ft. or nearly $10\frac{1}{2}$ miles. This record was beaten in 1933 by Cmdr. Prokofiev of the Red Army, accompanied by two Soviet scientists. They reached 62,320 ft. Their achievement was eclipsed in the following year by three of their comrades, who reached 72,178 ft., but unfortunately they lost their lives in the attempt. In 1935, the U.S. balloon, *Explorer II*, with Captains Stevens and Anderson aboard, ascended to 72,395 ft. (about 13·7 miles). These various records are all shown diagramatically in Fig. 1.

RECORD ALTITUDE FLIGHTS

Aeroplanes have not been able to reach such record heights, but this is not surprising in view of the extremely rarefied atmosphere at such high altitudes. Sponsored by the British Air Ministry, Captain C. F. Uwins reached 45,000 ft. in 1932, and four years later Lieut. F. D. R. Swain of the R.A.F.

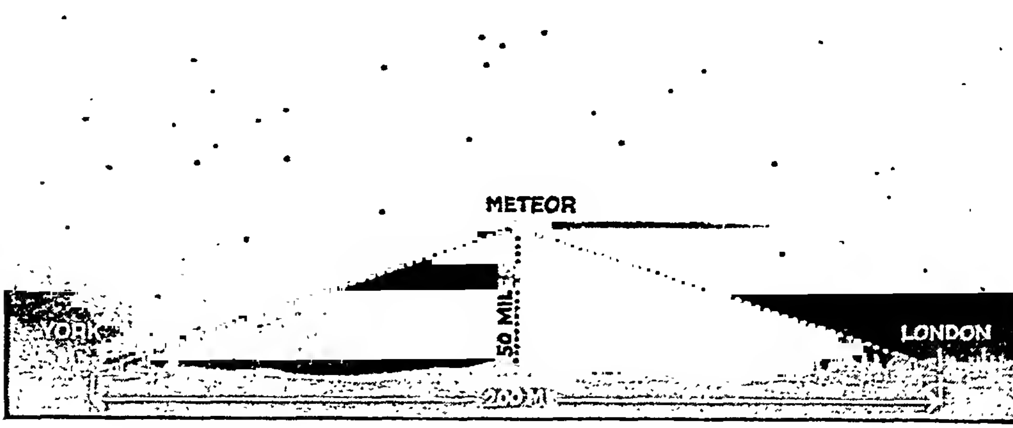


Fig. 2. How the height of a meteor is measured. The figure is explained on this page.

reached 49,967 ft. In 1937, Flight-Lieut. M. J. Adam of the R.A.F., reached 53,937 ft., his instruments registering a temperature of 48·9° C. below zero. This record was beaten in October 1938 by Colonel Pezzi, of the Italian Stratosphere Experimental School, who reached a height of 56,016 ft. at which the record now stands. Small unmanned balloons, carrying recording instruments, reach altitudes of about 25 miles—far greater than can be reached by man (Fig. 1).

None of these experimental flights enable us to determine the absolute limit beyond which there is positively no air. Even if we could reach greater heights, the atmosphere would be so rarefied that even the most delicate instruments would be incapable of recording any pressure.

ABOVE THE STRATOSPHERE

Above the stratosphere is a peculiar atmospheric layer discovered by Lindemann and Dobson, to which we shall refer again in our section dealing with Sound. Beyond this is the Heaviside-Kennelly layer, 70 miles above the Earth. At double that height is the Appleton layer (Fig. 1). These are layers of ionised gas that act as mirrors for radio waves, reflecting them earthwards again, so that it seems impossible that we should ever be able to send radio signals to Mars or other planets. The Heaviside-Kennelly layer reflects medium radio waves and the Appleton layer the short ones. Further away in space are other "layers" that reflect radio signals at from three to thirty seconds after transmission, showing that they must be situated at about 280,000 miles and ten times that distance respectively, as the velocity of radio waves is the same as light—186,000 miles per second.

Most of our knowledge as to the ultimate extent of the upper atmosphere is gained from the observation of meteors. As we have seen in an earlier chapter, these small bodies travelling in space remain invisible until they enter our atmosphere, drawn to the Earth by gravity. Thus, if we can ascertain the height of a meteor we know that at that height there is still atmosphere.

To determine the height of a meteor it is necessary to make observations from two points. Let us suppose that a meteor is simultaneously observed from York and London. To each observer the meteor appears at a certain angle above the horizon, and in a certain direction. The distance between

the two observers is already known, and when the angle of altitude and direction at which each observer sees the meteor has been also discovered, elementary trigonometry will enable us to calculate the height of the meteor (Fig. 2). From numerous observations such as this we find that there is air of sufficient density to afford resistance to the passage of meteors at a height of at least 200 miles. Probably the atmosphere extends to an even greater height in an extremely attentuated form.

WEIGHT OF THE AIR

At the first thought one would not suppose that air has weight, but this is made evident by the fact that smoke does not sink to the ground. A moment's thought as to the reason for this will result in our determining that the particles of soot and ash composing the smoke must be lighter than the air in which they float, and therefore we draw the conclusion that air must have weight.

We can prove that air has weight by weighing an electric lamp bulb on a good balance. Having done this, a hole is made in the globe with a blowpipe to allow the entry of air to fill the vacuum. If the bulb is again weighed it will be found to weigh slightly more than before, for we are now weighing also the volume of air contained in the bulb. A similar experiment may be carried out by boiling some water in a flask. Having done this we insert an air-tight stopper. As the water has expanded by being heated, there will be a partial vacuum in the flask when the water has cooled. In this state we weigh the flask and water and having done so we then remove the stopper, allowing air to rush into the flask. If we weigh the flask again we shall find that it weighs slightly more than it did before, because we are now weighing also the air that has filled the vacuum. A flask that has a capacity of 1 cubic ft. will show a difference of $1\frac{1}{4}$ oz. when weighed exhausted of air and with air. Normally, 100 cubic inches of air weighs 31 grains, or to put it another way 1 lb. of air represents 13 cubic ft.

There is a tremendous bulk of air in the atmosphere, the comparatively light weight of which can soon become a formidable item. Even the weight of air contained in a room can be considerable, for in a room 20 ft. square and 20 ft. in height the air will weigh over 600 lb. In a theatre or a large hall the air may weigh as much as a hundred tons or more.

Owing to the fact that air has weight, the atmosphere exerts a pressure on all objects equally in all directions. Under ordinary conditions the pressure of the atmosphere at sea level is nearly 15 lb. to the sq. in. As the atmosphere is lighter as the distance from sea level increases, the pressure correspondingly decreases in intensity.

USES OF THE BAROMETER

We can make use of atmospheric pressure in several ways as, for example, in the barometer (Greek: *baros*, weight; and *metron*, measure). This instrument enables us to measure the variations in atmospheric pressure, and, by applying our knowledge, to obtain information about probable weather conditions. The column of mercury in a barometer is held in position by pressure of the atmosphere on one end of the tube in which it is contained (Fig. 3). Any variation in the atmospheric pressure causes an alteration in the height of the mercury, even though this variation may be only slight. An increase in atmospheric pressure causes the mercury to rise higher in the tube and a decrease in atmospheric pressure similarly causes the height of the mercury to be lowered.

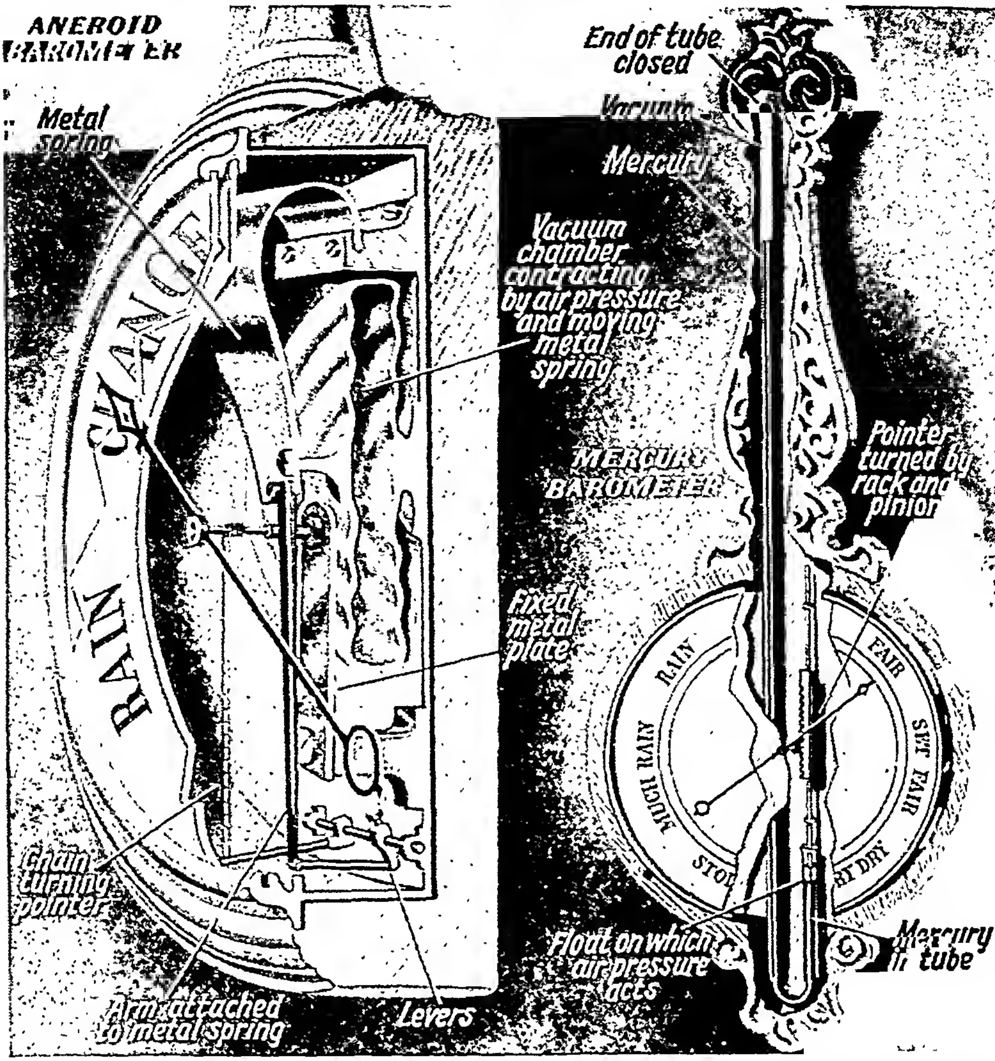


Fig. 3. (Left) Aneroid barometer, cut away to show its internal arrangement. (Right) Mercury barometer showing how a change in air pressure acts on a column of mercury, so moving the pointer. The pointer of the aneroid is moved by the contractions and expansions of a vacuum-chamber.

The aneroid (fluidless) barometer, does not as its name implies, depend on liquid mercury but consists of a metal chamber from which the air has been exhausted (Fig. 3). Bearing on the top of the box is a steel spring capable of moving with the top of the chamber and attached to a multiplying lever that operates a spindle and pointer. The varying atmospheric pressure causes the top of the chamber to rise and fall, for as it encloses a vacuum there is no pressure inside to support it so that it must respond to outside pressure. Thus the pointer indicates the varying atmospheric pressure and since the indicator scale is graduated to correspond with the standard mercury barometer, the readings are identical. The indicator may be fitted with a recording pen that marks a record of the readings on a chart arranged on a drum revolved by clockwork (Fig. 4). These records, or "barographs", may be seen at meteor-

ological stations and often in opticians' shop windows.

The reason why the barometer can be used in foretelling weather conditions arises from the fact that changes in the wind result from changes in atmospheric pressure and wind is the chief factor in changes in the weather. Wind is simply the movement of great masses of air from areas where the pressure of the air is high to areas where it is low. When that air is moisture-laden (*e.g.*, has come over the sea) it will bring rain. In Britain the south-west winds bring rain from the Atlantic. When our barometer falls we know that rain will soon be with us, for we are in an area of low pressure.

IMPORTANCE OF OXYGEN

We have explained that with an increase in height the air becomes more rarified. Piccard and the other explorers of the stratosphere, as well as the high-altitude aeroplane pilots, found it necessary to inhale oxygen from special breathing apparatus. Similarly, oxygen was used in the final stages by the expeditions that have attempted to conquer Mount Everest, the world's highest mountain, which rises to 29,002 ft. The existence of all life depends on this odourless and colourless gas, whether on land or in the sea. So sensitive are our organs and senses to the presence of oxygen that they are able to detect a difference as minute as 0·107 per cent. in the quantity present. Thus, as the air is so rarified at great heights the absence of the necessary amount of oxygen has a deleterious effect on the system, to combat which additional supplies are inhaled from the apparatus.

Oxygen and nitrogen in the approximate ratios of 21 to 79 volumes are the main constituents of the atmosphere. Oxygen is the active agent and is diluted by the nitrogen, its activity being thus decreased. There are also present in the atmosphere: water vapour, small quantities of other gases including carbon dioxide—the deadly gas that is exhaled in breathing—and also large quantities of dust.

Dust plays a very important part in atmospheric phenomena and to a great extent is responsible for the blue of the sky. The light rays are scattered by the fine dust particles, and as the blue

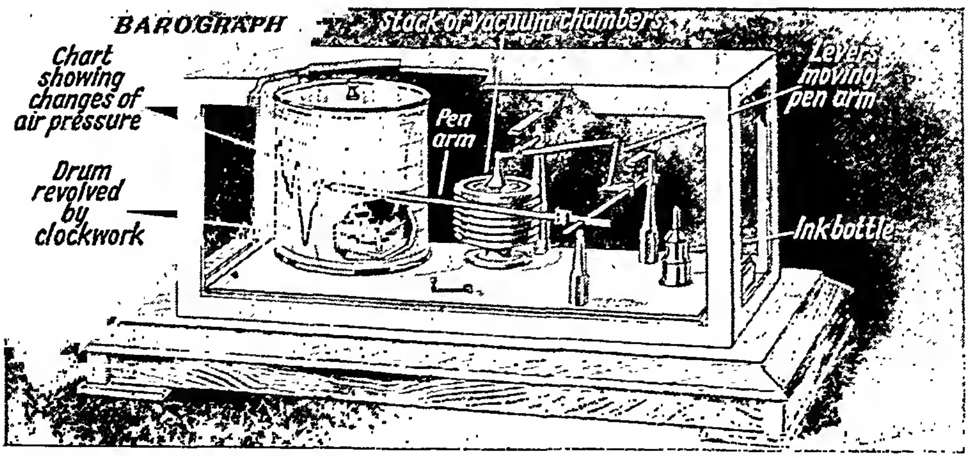


Fig. 4. The Barograph or recording barometer, which works on the same principle as an ordinary aneroid barometer. The expansions and contractions of the vacuum-chambers operate a pen which records the degrees of pressure-variation on a chart wound round a revolving drum.

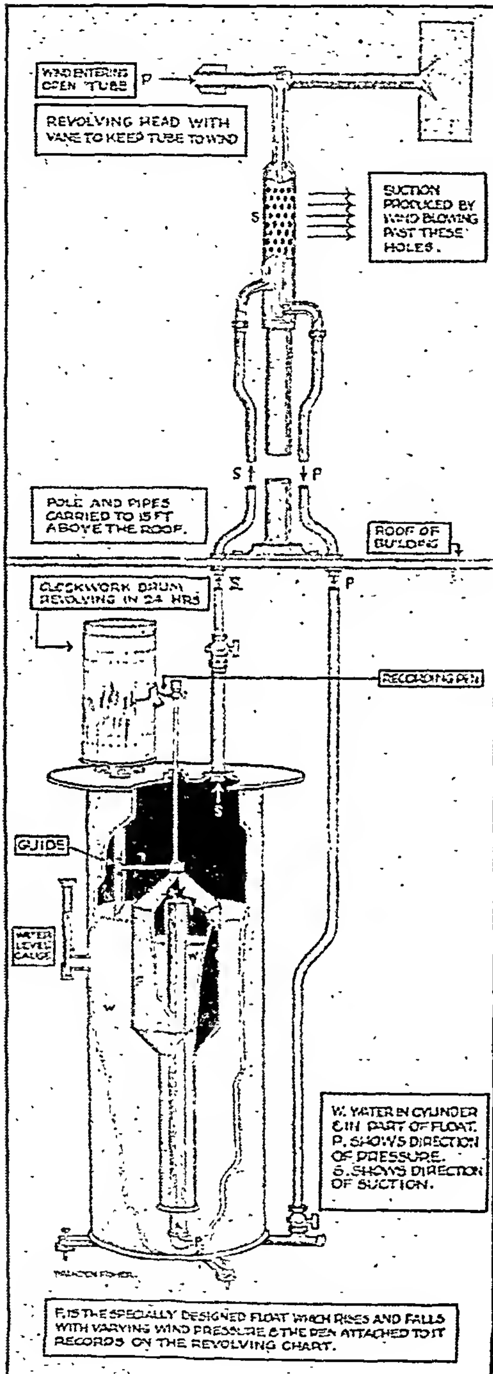


Fig. 5. Showing the workings of the anemometer, by which the force of the wind is registered, thus enabling the velocity to be calculated. This instrument gives very accurate and consistently dependable recordings.

rays are scattered further than the red the sky appears blue. Without the presence of these fine particles the sky would appear black and the stars would be visible in daylight. Counts have been made of the dust particles contained in air taken from different places. Air from above the Indian Ocean was found to contain 7,600 particles to the cubic inch, whilst over the Atlantic the number of particles was found to be 30,000. Generally speaking, over land the particles have been found to be more numerous and counts have resulted in as many as 60,000 per cubic inch.

IMPURITIES IN THE ATMOSPHERE

Dust may remain suspended in the air for long periods and will travel over considerable distances. Dust from Africa has fallen on vessels in the Atlantic, having travelled 1,000 miles or more after being raised high into the air by one of the prevailing hot winds that blow from the Sahara Desert. Sometimes the dust particles are so minute that they may remain suspended in the atmosphere for months or even years, before they finally fall to Earth. After the eruption of Krakatoa, to which we have already referred, volcanic dust was driven into the upper atmosphere to a height of 20 miles. Here it was caught by air currents and carried around the Earth, making a circuit in 13 days. In some places it caused the Sun to appear blue and the Moon green. Wonderful sunsets were seen for several months, the particles of dust being of sufficient density to refract and reflect the rays of the setting Sun, causing marvellous colour effects. Not until two years later did the dust particles finally subside.

Dust and moisture in the atmosphere to a large extent determine visibility (the distance over which we are able to

see). If the air is clear and dry, visibility will be good and objects may be seen at great distances. For instance, the lights on the top of the mountains in Corsica have been seen from the northern coast of France, a distance of 168 miles. In California, lights reflected from mirrors on Mount Shasta were seen from Mount Helena, 192 miles distant, which is a record for long-distance vision. Long-distance photographs taken at an altitude of 23,000 ft. with film sensitive to infra-red rays shows Mount Shasta from a distance of 331 miles (see Chapter 6, Fig. 3).

Our atmosphere is seldom still—storms, winds, breezes, and zephyrs keeping it in constant movement. The more violent movements are due to large-scale movements of air from one region to another. These movements take place because air when heated expands, and when cooled contracts. Thus when a region is subjected to a change of temperature there is a change in the air in that region, resulting in regions of high pressure and regions of low pressure.

RADIATION FROM THE EARTH

The amount of radiation received from the Sun is much greater in the equatorial regions than in the polar regions, whereas the amount of radiation lost is practically the same for all parts of the Earth. The polar regions part with more heat than they receive directly from the Sun, the balance being made up by the movement of warm currents of air from the equatorial regions. The movements of these air-currents are complicated by the rotation of the Earth; otherwise there would be a constant and regular circulation of the air as it passes from the equator to the poles. As it is, however, there are some uniform changes of temperature that cause regular winds, the existence of which has been known for a long time.

The force of the wind may be registered by the anemometer, and from the record so obtained the velocity may be calculated. An anemometer may consist of four metal cups, or half-spheres, mounted horizontally on a vertical rod, and made to rotate at speeds that vary with the force of the wind. By suitable gearing from the base of the vertical rod a dial indicates the rate of travel of wind passing the cups. In a more elaborate form of instrument the information is recorded by a pen on a paper strip fastened to a rotating drum, as in the barograph or recording barometer. In this case the pressure and suction effects of the wind are made to act on a float contained in a closed vessel, to which is attached a light spindle that carries the recording pen (Fig. 5). The effects of pressure and suction are converted into a uniform scale of velocity, the resulting record showing each "gust" and each "lull", whatever the velocity.

To give some idea of the normal wind velocity we may mention that the mean speed of the wind at Southport during 1937 was 12·9 miles per hour, a figure that is 2·1 miles per hour below a thirty years' local average. The greatest wind velocity for one hour at Southport in 1937 was 50 miles per hour (28th February). The greatest velocity during a gust in the same year was 71 miles per hour (28th February). The greatest wind velocity in the British Isles was the 111 m.p.h. recorded on 6th December 1929 at the Scilly Isles.

THE BEAUFORT WIND-SCALE

The force of the wind is expressed by what is known as the Beaufort Scale, because it was devised by Sir F. Beaufort. The scale ranges from 1–12, and although it makes no reference to the velocity of the wind, attempts have been made to

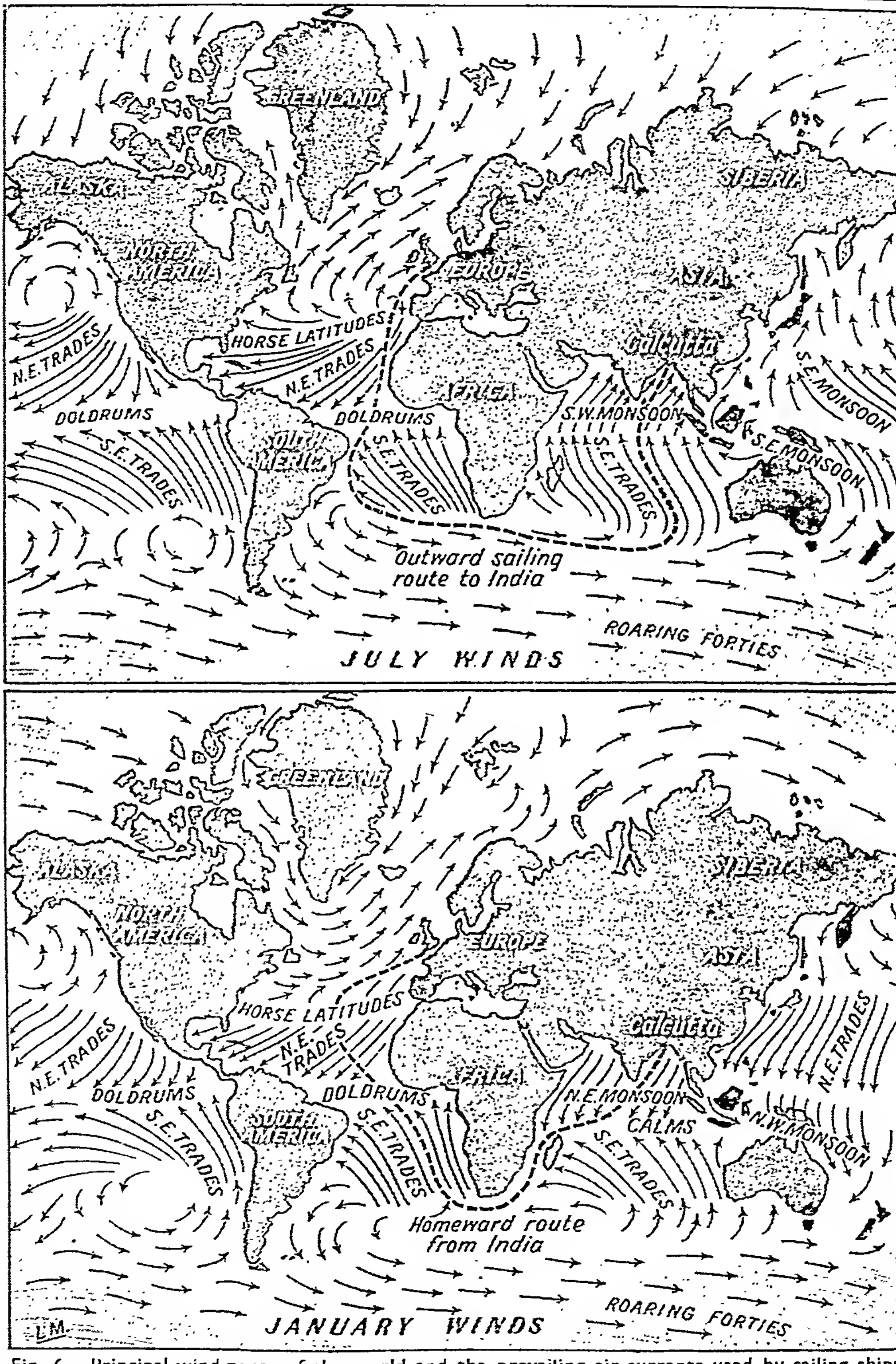


Fig. 6. Principal wind-zones of the world and the prevailing air-currents used by sailing ships.

correlate the two factors. In 1906 the Meteorological Office adopted the following scale:

Beaufort Scale	*Description*	*Velocity in miles per hour*
0	Calm	Under 2
1–3	Light breeze to gentle wind	2–12
4–5	Moderate to fresh wind	13–23
6–7	Strong wind to moderate gale	24–37
8–9	Fresh to strong gale	38–55
10–11	Whole gale to storm	56–75
12	Hurricane	Over 75

In each hemisphere there are three well-defined wind-zones. One is formed by the flow from the polar regions; another by that from the equatorial regions; and a third by those that blow from west to east (Fig. 6). In some regions the winds are never strong, and here there are long periods of calm—as at the poles, near the tropics, and at the equator. In the equatorial region of calm, known as the "doldrums", the old sailing ships were often becalmed, sometimes for weeks at a time.

The constant heat at the equator heats the air so that it is always rising, its place being taken by the cooler air from the temperate zones. As a result, the winds within the tropics blow steadily all the year round, the breeze being strongest in the mornings and evenings. So regular are these winds that they were known to sailors as the "trade winds". It was these winds that enabled Columbus to sail across the Atlantic, and Magellan to sail across the Pacific.

Some other winds are also specially named according to their particular characteristics. There is, for instance, the "bora", a cold wild wind that sweeps down from the Alps to the Adriatic and Black Sea. It blows with such fury that a gun cannot be heard and no fire kept alight, and sometimes it will even overturn heavy wagons and carry away their horses and drivers. In the Gulf of Lyons, the "mistral" blows strongly from the north-west. It, too, originates in the Alps and its approach is heralded by white cotton-like clouds that appear in the sky. The "gregale" of Malta is a somewhat similar cold dry north-east wind, as is the "purga" of Italy, and the "northers" of Texas. The last-named sweep from the prairies to the Gulf of Mexico, often causing great destruction.

Hot winds, such as the "simoon" of Africa and Arabia, are caused by the intense heat of summer—sometimes sufficient to heat the sand to 200° F. at a considerable depth. This causes the air to expand and rise, blowing over the desert to the adjacent countries as a hot current of air and fine sand that almost suffocates man and beast. A very similar wind, the "sirocco" of Southern Italy, rises in the Sahara but is somewhat tempered by passing over the Mediterranean. The harmattan of Cape Verde and the coast of Guinea dries up every drop of moisture in its path.

WHAT ARE THE MONSOONS?

Monsoons occur in the Indian Ocean and the China Sea, and navigators from a very early period have taken advantage of them to make quick passages. They blow with great force and regularity in the Mozambique Channel, along the east coast of Africa, over the northern Indian Ocean, the Gulf of Aden, Arabian Sea, and Bay of Bengal. In the Indian Ocean a north-east monsoon blows when the Sun is in the southern hemisphere and a south-west when it is in the northern. Monsoons are a development of the trade winds and are due to the

Fig. 7. A tornado passing over David City, Nebraska. It travelled a few miles doing great damage, then disappeared into the sky. A tornado may be described as a revolving wind-storm.

intense heat of the great land masses of South Asia and North Africa in May and June and of North Australia in November and December. This causes a great rush of air towards these land masses, from the south-east or south-west when the Sun is north of the Equator and from the north-east and north-west when it is south.

Cyclones and tornadoes (Fig. 7) are more intensive than monsoons—they are more local in character and of a temporary nature, and may better be described as revolving windstorms. They occur in the Indian Ocean and in the Pacific and China Seas, where they are called typhoons. The West Indies know them as hurricanes or whirlwinds, and in Australia the same kind of storm is called the "willy-willy" These revolving storms may cause enormous damage. They move at speeds of a hundred miles an hour or more and occasionally attain enormous velocities—the one that laid waste the city of St. Louis in 1896 reached the stupendous speed of 558 miles an hour. They cover an area of from twenty to some hundreds of miles and are generally preceded by oppressive heat, followed by a short period of ominous calm. Then the leading edge of the storm approaches and strikes with tremendous force; is followed by a period of comparative calm, after which the following edge of the storm arrives, the force of the wind then being in the opposite direction.

A cyclone that struck the West Indies in 1851 travelled over a distance of 2,500 miles, destroying much valuable property and causing the deaths of 1,477 persons. Houses were razed to the ground and ships torn from their anchorages and cast on the shore. At Calcutta in 1804 a cyclone resulted in

over 60,000 people losing their lives, the destruction of numerous towns, and the loss of over 100 ships. Three years later another cyclone resulted in the deaths of 90,000 people and the destruction of 30,000 houses in Lower Bengal as well as a considerable amount of shipping. A more recent cyclone—and one of the most disastrous of modern times—occurred at British Honduras in 1931. Within half an hour of its arrival all the churches were wrecked and there was not a building undamaged. A 200-ton dredger was lifted bodily out of the sea and dropped on the roof of the Customs House some way back from the quayside.

The storm was followed by a mountainous wave that threw ships and barges high and dry on shore. Then came a fire that completed the work of destruction.

These cyclones are closely allied to the hurricanes that frequently sweep the Atlantic coast of the United States. One of the most recent of these storms—that of 21st September, 1938 (Fig. 8)—caused enormous devastation and ruin over a great area in the New England States. All communications were destroyed, so that knowledge of the plight of the stricken inhabitants and speedy assistance for them were alike delayed. Whole sections of towns were devastated, and large tracts of land were flooded. This hurricane was stated to be the worst that America's Atlantic seaboard has known for half a century. The coast lies close to the normal track of the hurricanes that originate near the Equator and sweep across the West Indies, then turning north-eastward.

MYSTERY OF HURRICANES

These cyclonic hurricanes are most frequent about September. In 1926 and 1935 great hurricanes scourged Florida. In 1936 one swept the coast of the Carolinas and Virginia, driving thousands from their homes and flooding dozens of towns. Some attempt has been made to arrange a system of

Fig. 8. Fearful devastation was caused by a hurricane on 21st September, 1938, along the Atlantic seaboard, particularly in the New England states. This picture shows the whole front of a house torn out by the gale. On some occasions whole buildings are razed to the ground.

hurricane warnings in the United States, but such warnings can only enable people to get into places of relative safety. Too little is known of the causes of hurricanes to permit long-range forecasting. Why in some years they are much more frequent and violent than in others is one of Nature's mysteries.

NATURE OF A TORNADO

A tornado is similar to a cyclone, its vortex, or funnel of wind, reaching high up into the sky. It is more local than a cyclone and may cut a path 30 miles in length but perhaps only 1,000 ft. in width. The path of a tornado is so narrow and so well-defined that people might escape by running out of it. At the centre of the vortex is a vacuum, the effect of which is to cause the atmospheric pressure inside buildings to blow outwards the roof and the walls, so that the result is virtually an explosion inside the house. Some curious phenomena are seen during a tornado. Straws have been driven into trees and timber fences as though they were steel rods. During a tornado at Calcutta a bamboo cane was driven through a mud wall 6 ft. thick and lined on each side by a course of bricks.

Although a tornado seldom lasts for more than an hour, and for not more than a minute or so at any one place, its destructive effect is very great. It seems to make up in increased violence for the shortness of its duration. Houses may be lifted from their foundations, wagons hurled through the air, and people, animals, and wreckage, carried for considerable distances. In 1931 a tornado at Dakota, U.S.A. wrecked one of the fastest and most luxurious trains on the Great Northern Railroad, lifting the whole train off the track.

Tornadoes are probably caused by eddies formed by two masses of air moving in opposite directions at high speed. In the United States there are about a hundred tornadoes every year, in the States of the Middle West. The storms commence on the prairies east of the Rocky Mountains, where the north winds of the eastern slopes brush past the south winds of the Mississippi Valley.

A similar occurrence taking place over the sea results in a water spout, the vacuum of the vortex sucking up water from the ocean and apparently drawing water from the clouds. The two cones of water, both in rapid rotation around their centres, meet; at the same time the waterspout travels across the sea in a direct line. Waterspouts vary in diameter from two to 200 ft., and may extend to heights of 1,500 ft. or more, moving at from walking pace to 4,000 ft. a minute. Strange as it may seem, there have not been many instances of damage to shipping by waterspouts, although five vessels were once sunk in the harbour at Tunis. Waterspouts over land seem to have been responsible for more destruction, having caused damage at various times in Kent, Cornwall, Killarney and elsewhere. In 1856 a 1,500 ft. waterspout near Calcutta covered half a square mile with water to a depth of 6 in.

EFFECT OF DUST IN THE AIR

We have already referred to the large amount of dust particles suspended in the atmosphere. These dust particles help to cause fog, for the water vapour in the atmosphere condenses on them because they cool more rapidly than the air through which it passes. Each dust particle becomes the nucleus of a globule of moisture, perhaps ·01 in. in diameter, that falls to Earth only slowly, the attraction of gravity being almost balanced by the friction of the air through which they pass. Each globule carries a minute electrical charge

and this causes them to repel each other, so that they do not coalesce to form drops of water. Further condensation of water vapour on the globules may cause them to grow larger, however, when they sink through the air more quickly. Should they be subjected to

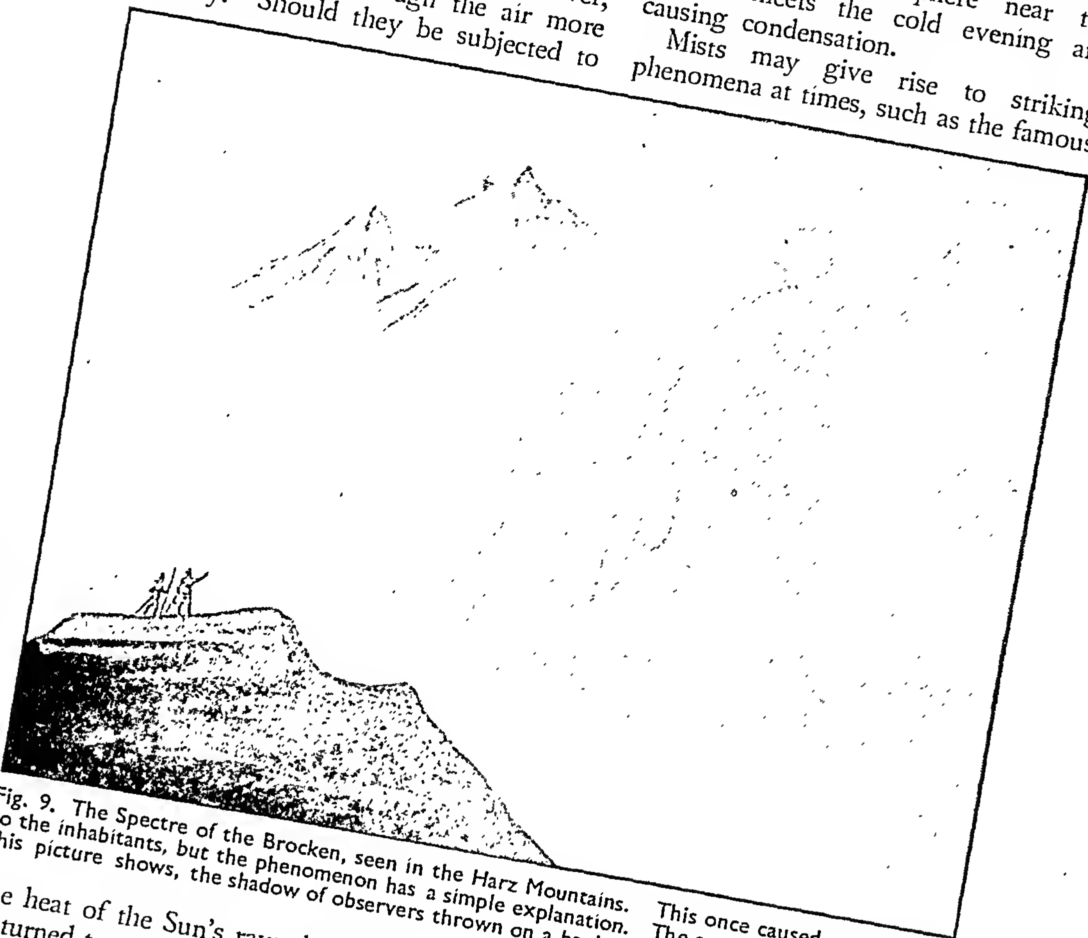


Fig. 9. The Spectre of the Brocken, seen in the Harz Mountains. This once caused great terror to the inhabitants, but the phenomenon has a simple explanation. The so called "spectre" is as this picture shows, the shadow of observers thrown on a bank of mist that rises from the valley.

the heat of the Sun's rays the moisture is turned to vapour again and the fog is dissipated.

Fog is not always caused by dust, it may be due to drifts of moisture-laden air meeting drifts of cold air. This occurs notably off the coast of Newfoundland, where there are almost perpetual banks of fog caused by warm air from the Gulf Stream meeting cold air from Labrador and the Arctic. Similarly in Britain we get mists in spring and autumn at sunset, when the warm moisture-laden atmosphere near the ground meets the cold evening air, causing condensation.

Mists may give rise to striking phenomena at times, such as the famous "Spectre of the Brocken" (Fig. 9). The Brocken is one of the highest of the Harz Mountains, and here is seen the curious effect to which the mountain has given its name. Actually the "spectre" is the shadow of the observers thrown on a bank of mist that rises from the valley, the appearance being that of a ghostly image of men of colossal dimensions, dark as a whole but bounded by a coloured outline. To the

superstitious and timorous peasants of the region the appearance was ascribed to a huge demon who inhabited the mountains, striding from peak to peak with supernatural ease.

Similar "spectres" are to be seen in other parts of the world, wherever there is a convenient screen of mist and when the lighting is from the appropriate quarter. Balloonists sometimes see a somewhat similar effect, the enlarged image of the balloon surrounded by luminous rings being projected on to the clouds below, while they themselves are in bright sunshine. Aviators, too, see these "anthelions" when flying over a sea of cloud, a luminous circle exhibiting all the colours of the rainbow—for it is indeed a complete rainbow. In the centre of the circle the aviator sees a shadow-image of his aeroplane.

WHAT CAUSES CLOUDS?

The condensation of the water vapour in the atmosphere, by which fog and mist are formed, accounts also for the formation of clouds, which may be regarded as accumulations of mist at a high altitude above the Earth. The amount of moisture that can be held as vapour in the atmosphere depends on the temperature, for air at high temperature will hold more water than when at low temperature. As a gas, water vapour is of course, invisible, but should the temperature fall below the critical point the molecules draw together and form drops of liquid. This is called condensation and is the opposite process to evaporation.

When the atmosphere is carrying so much water vapour that only a slight lowering of the temperature will cause condensation, it is said to be at saturation point. At a temperature of 32° F. air can contain $\frac{1}{160}$ part of its own weight in the state of vapour. With every 27° increase in the temperature the amount is doubled, so that at 59° F. it can contain $\frac{1}{80}$, and at 86°, $\frac{1}{40}$ of its own weight. It is easy to understand that actually there may be more water vapour in the atmosphere in the summer than in the winter, for the temperature then is higher. Why we feel that the atmosphere is drier in summer than in winter is because the air could evaporate more water vapour than it has done and is, as it were, unsatisfied in this respect.

When the atmosphere is saturated with water vapour it condenses even if the temperature be lowered only slightly, and the molecules form droplets of water so small that they have been appropriately called "water dust". This may occur when saturated warm air ascends to a higher altitude where the temperature is lower. When this occurs the condensation of the water vapour forms a mass of innumerable droplets, and this we call a cloud. Should the cloud of moisture again come in contact with a current of warm dry air the droplets are converted back to water vapour. Thus we can easily understand why the clouds are ever-changing, for the water is continually being changed from liquid to gas. Not only is this due to the alternating currents of air but also to the fact that the droplets themselves slowly sink by the action of gravity, eventually reaching a layer of air that is of a sufficiently high temperature to evaporate them.

MATTERHORN CLOUD-BANNER

These constant changes cause interesting phenomena to occur on the tops of some mountains that are peculiarly situated. On the Matterhorn we have the "cloud-banner", a streamer of cloud apparently clinging tenaciously to the mountain and held steady for long periods, almost like smoke from a factory chimney (Fig. 10). Actually, the extremity of the "cloud-banner" is con-

Fig. 10. The Matterhorn, showing the famous "Cloud-banner" that hangs from the peak like smoke from a chimney. This banner is nearly always to be seen.

tinually being dissipated into the atmosphere, the banner being as quickly renewed at the other end, so that it is as though a river of cloud is being sent up from the mountain. The explanation of this phenomenon is that air charged with moisture comes in contact with the cold peak of the Matterhorn; the

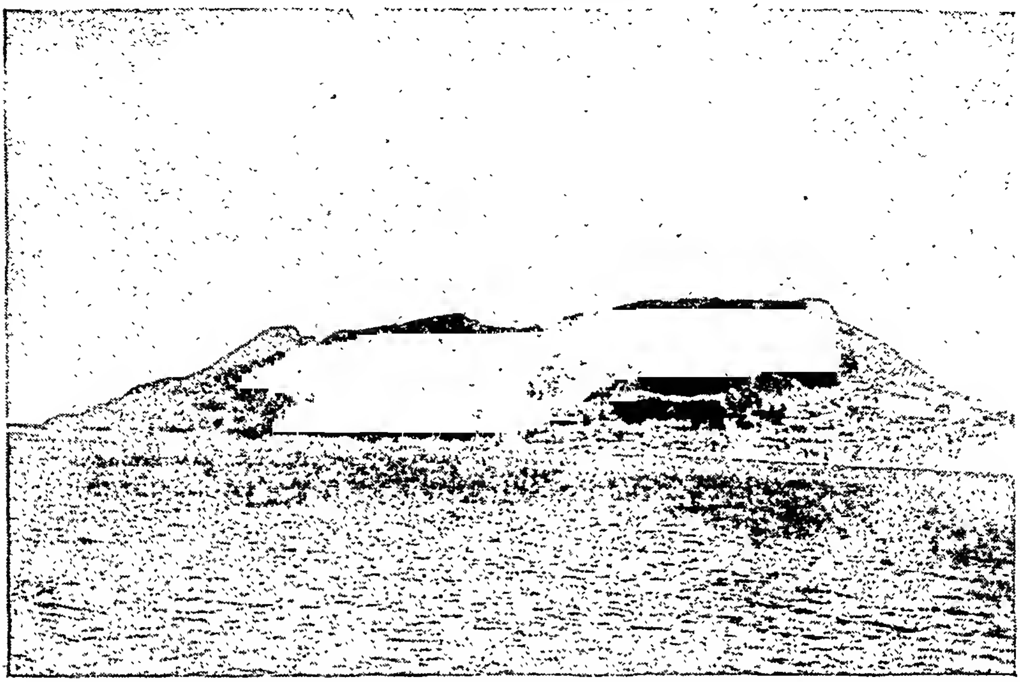


Fig. 11. The Rock of Gibraltar with the famous "Plume". This curious cloud is always to be seen over the Rock whenever the "Levanter" wind is blowing.

vapour is chilled, and the water content is condensed so that the summit appears to smoke almost like a volcano.

A similar phenomenon occurs at the Cape of Good Hope, where Table Mountain is seen to be covered with cloud. This "spreading of the table cloth", as it is called, is due to air from the Indian Ocean, saturated with water vapour, condensing into a thick white cloud when cooled by contact with the mountain. The cloud covers the flat mountain top and rolls down over the opposite side. Halfway down it meets warm air that again vaporises the water so that the cloud does not succeed in reaching the foot of the mountain. At Gibraltar, too, the "Plumë" forms over the rock when a Levanter is blowing from the East. The Rock deflects the warm air into a higher altitude where the air is cooler, and the moisture is then condensed into cloud which streams steadily away to the west (Fig. 11).

The formation of different kinds of clouds is affected by various considerations, chiefly height, temperature of the atmosphere, air currents, and the constituent particles forming the cloud. These last-mentioned may be droplets of water, as we have already explained, or in some cases they may be tiny frozen particles of ice.

THE GROUPS OF CLOUDS

At the beginning of last century clouds were divided by Luke Howard, an eminent meteorologist, into three main groups, and on this scheme is based the present classification. To-day, ten classes of clouds are recognised, and are arranged according to the altitude at which they occur. Without going into a detailed classification we may take Howard's three main groups as representative.

First, there are the Cumulus clouds, generally dense and compact in appear-

ance, having a more or less horizontal base and an average altitude of about 5,000 ft. (Fig. 12). These are the clouds that look like wool packs and they foretell or accompany fine weather. Sometimes they are of enormous extent, and as a rule they attain their greatest size early in the afternoon when the day is hottest. Before rain they increase rapidly in size and appear to be lower and with their lower surfaces less distinct than when the weather is fine.

SUNSET CLOUDS

The second group of clouds is the Stratus, generally low-lying, flat sheets of cloud that stretch across the sky. They are generally seen near the horizon, and at sunset they present a beautiful appearance. "Weather prophets" regard them as a sure sign of fine weather when they appear at sunrise or sunset. They form so quickly that on a calm night a cloudless sky may be covered by them from horizon to horizon in less than ten minutes.

The third group is the Cirrus—delicate, white, fleecy clouds that stretch across the sky or range in parallel belts. These clouds have the least density of any, and the greatest variety of form. They float only in the upper regions of the atmosphere and generally are from 5 to 10 miles above the Earth. It is these clouds that are composed of minute ice crystals and cause haloes of the Sun and Moon. Sometimes cirrus clouds may be seen extending from one horizon to the other. They may remain visible for only a few minutes or may persist for some hours. Observations of cirrus clouds are of great value to meteorologists, giving the first indications of a coming change in the weather.

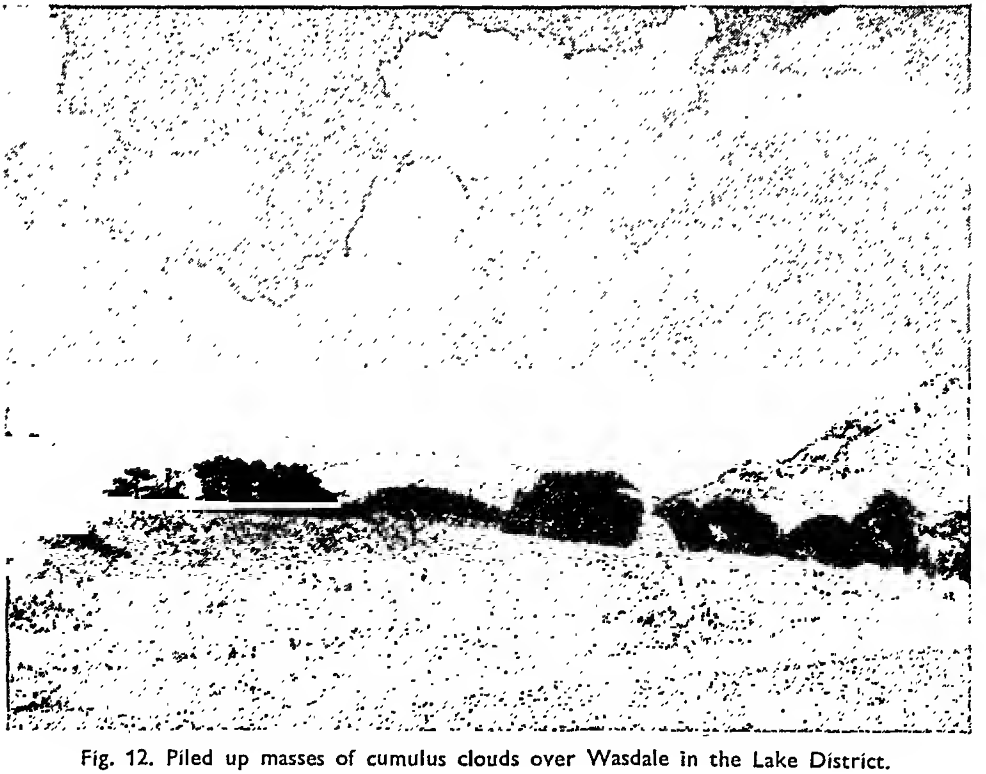


Fig. 12. Piled up masses of cumulus clouds over Wasdale in the Lake District.

When their edges become indistinct rain may be expected soon, but when their edges are clear and well-defined fine weather may be expected to continue for some days.

Generally speaking, all clouds are at an altitude of over 3,000 ft. and they are higher in summer than in winter. They travel across the sky, driven by air currents or the wind, at speeds that vary with their height. As the velocity of the wind is generally greater at higher levels, and greater in winter than in summer, it is safe to say that as a general rule, the higher the cloud the greater the speed of travel. Cirrus clouds at 30,000 ft. have been observed travelling at 150 m.p.h.; cumulus clouds at 5,300 ft. at 24 m.p.h.; and stratus clouds at 1,670 ft. at 19 m.p.h.

WHY CLOUDS CAUSE RAIN

Everyone knows that there is a close connection between clouds and rain. We have seen that a cloud consists of droplets of moisture and that these droplets may grow in size by the increasing condensation of moisture. Although the original droplets are of small mass they have a comparatively large surface, causing them to resist any tendency to sink to the Earth. If the droplets are not evaporated by encountering warm air, additional condensation may cause them to increase in size. The surface is not increased in the same proportion as the mass, however, for the weight of a sphere is in proportion to its volume. The consequence is that the air can no longer support the larger drops and these fall to Earth as rain. If they fall through moist air in their descent they gather more moisture and become larger and larger, a process that accounts for the varying sizes of raindrops.

Records of the amount of rain that falls are kept in most places by means of a rain gauge. This is a simple device of a funnel and a bottle or can of uniform size, the object being to collect all the rain that falls in a given area and to store it without evaporation until it can be measured. The Snowdon pattern rain gauge (Fig. 13) has a rim 5 in. in diameter and is placed with the rim 1 ft. above the ground. It delivers the rain water it collects into a bottle that holds 3 in. of water, the amount collected being measured to two places of decimals on a graduated glass. The marks on the glass show the depth to which the rain would lie if it neither flowed away nor soaked into the ground.

As a cubic inch of water weighs 252·458 grains, and as a depth of ·01 in. of water over a 5 in. circle weighs 49·77 grains, it is not difficult to calculate that 1 in. of rain over an acre will weigh 101 tons, and will consist of 22,624 gallons or 3,630 cubic feet. In other words, a fall of 100 in. of rain is equal to about 1 ton of rain per acre.

"Mean annual rainfall" means all the rain, snow, or hail—indeed all forms of moisture that can be measured—that falls during a year on some particular locality. As the amount of rain differs in the same locality at different times, one year may be much wetter than another.

WHERE RAINFALL IS GREATEST

The amount of rainfall is greatest in the tropics and it is least at the Poles. In those continents not situated near the equator, it is greatest in mountainous districts—and especially in those near the sea where the prevailing wind is from the sea—and is usually smallest in the interior. The reason for this is that when a warm wind blows against a mountain it is diverted to the cooler and higher levels of the atmosphere. As cool air cannot hold as much water vapour as warm air, it condenses more easily and falls as rain. On the other

hand, by the time the wind has reached the opposite side of the mountain, the air has been robbed of much of its water vapour and there is less tendency to condensation and rainfall. Inland, where the temperature is more constant or increases, the moisture remains in the air as water vapour.

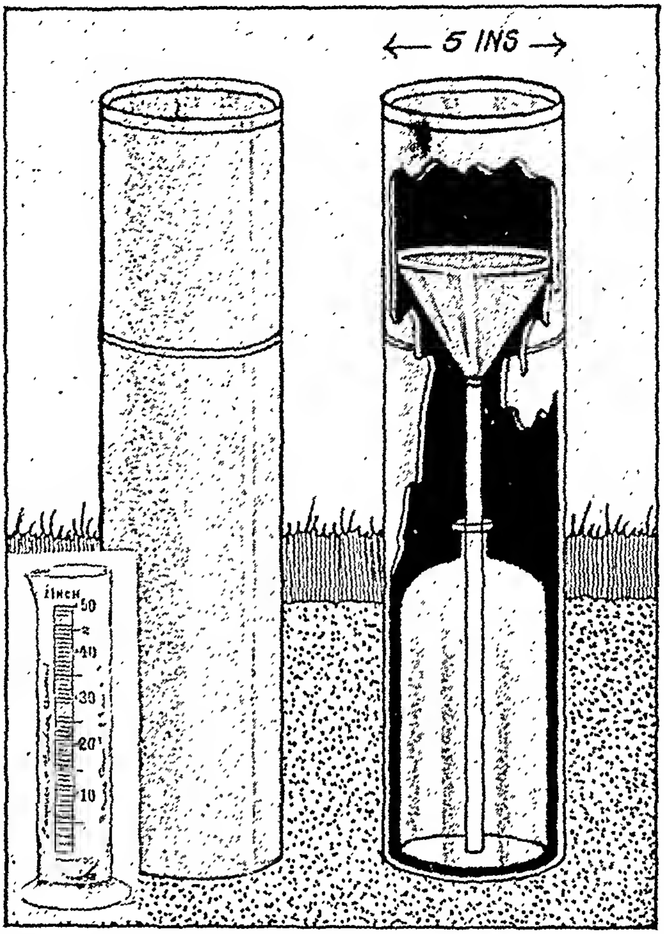


Fig. 13. Snowdon rain gauge with its five-inch brass rim. (Inset) The rain measure used with the gauge.

As a rule, rainfall is heaviest where the rainy days are fewest, and the number of rainy days increases with the distance from the hot regions on each side of the equator. There are places—in the Sahara and Gobi deserts, for example—where rain never falls, and others where no rain falls for three or four years at a time. On the other hand, in the Khasi Hills in Assam, just south of the Himalayas, 500 in. of rain falls annually—as much rain may fall in one day as London receives in a whole year! Among the world's other "wet spots" may be mentioned Mount Waialeale, in the Hawaiian Islands, where the average rainfall is 476 in. per annum. At Cherrapunji, Bengal, the average annual rainfall is 429 in. Here between 1st January and 31st August, 1938, 536 in. of rain fell.

In Britain, the annual rainfall varies from below 25 in. in some places to over 100 in. in parts of the Lake District. The average annual fall over the whole of Britain is about 34.3 in. As our prevailing winds are from the south-west, and as our mountains are in three groups, we may expect to find a higher rainfall in the mountainous districts—Cornwall, Wales and the Lake District—than elsewhere, for reasons already explained. In the West of England, the average rainfall is about 40 in., and the figure progressively decreases to the east, where it is about 25 in. In some parts of Cumberland the annual fall is over 75 in. and at Seathwaite, a village in Borrowdale, the average is about 146 in. each year. At Sty Head, about a mile away, the annual fall is even greater, being about 170 in. This is the

wettest place in Britain, and indeed holds the record for annual rainfall in Europe.

The lowest average rainfall in the country is the 23·3 in. of Cambridge, Margate, Lowestoft, and a few places in the Midlands. The greatest rainfall on any day in the British Isles was recorded at Bruton in Somerset, when (on 29th June, 1917) 9·56 in. fell, equalling 965 tons of water to the acre.

CONSTITUENTS OF RAINWATER

Although it generally contains some impurity—such as carbon dioxide—that it has taken up in its passage through the atmosphere, rain-water is the purest of all natural waters. This is more particularly true when the rain-water has been collected at places far from human habitation. It is because of its purity that rain-water is so "soft". It is insipid to the taste because it does not contain the minerals in solution to which we are accustomed in spring or tap-water. Absolutely pure water cannot be obtained in a natural state, nor indeed can it be prepared in the laboratory, although samples of highly purified water have been prepared and found nearly to approach the ideal. Rain-water may be purified by distillation, and to make more certain of its purity the water obtained in this way is re-distilled.

Rain-water contains more organic matter than well-water, because of the large quantities of fine particles from animal and vegetable waste and decay that are suspended as dust in the atmosphere. As we have already seen, it is on these particles that the water vapour in the atmosphere condenses, the ultimate raindrops bringing the organic matter back to the Earth.

Sometimes this natural process gives rise to curious effects, as, for example the shower of red rain that occurred in 1608 at Aix, when large red drops of liquid were seen on the walls of the cemetery and of the church. The inhabitants were greatly alarmed at what they regarded as a "shower of blood". The explanation probably lay in the fact that the rain had brought down with it a large number of *algæ* or tiny plants. Such *algæ* consist of microscopical spheres measuring less than ·001 in. in diameter and belonging to the simplest forms of vegetable life. Red rain has often been recorded subsequently, as at Vienna and in Italy in 1901, in Cornwall and Hamburg in 1902. In 1903 fine red dust from the Sahara was brought down by rain over the South of England.

Four showers of black rain fell in 1862 in Scotland, due probably to the presence of fine volcanic dust brought back to Earth from the higher atmosphere. Yellow rain, such as fell in Morayshire in 1854, can be explained by the presence of quantities of pollen lifted by the wind and brought down by the rain. Some years ago seeds of *veronica*, or speedwell, covered the ground in Silesia after a violent rainstorm, and seeds of ivy similarly were found in Wiltshire. Even this does not exhaust the marvels of rain, for on several occasions it has actually rained fish! In 1817 at Appin in Scotland there was a shower of small herrings, and again in 1830 at Islay in Argyllshire a similar phenomenon occurred. Some fifty years ago there was a shower of small frogs in Worcestershire, and in 1900 a similar shower occurred after a thunderstorm near St. Helen's.

All "miraculous" showers of this kind have similar explanations. The herrings—be it noticed that they were small—were lifted into the clouds by a waterspout at sea; the small frogs, either by a waterspout from fresh water or by a whirlwind.

CHAPTER 10

WATER IN ALL ITS FORMS

In the previous pages we have learned a good deal about water, and we may profitably pause to consider what water is and how it is formed, since it is not an element.

An element is one of the ultimate forms of matter that cannot itself be split into anything more simple. Any element (with the exception of argon) will combine with one or more other elements, so forming a compound. Thus everything is either an element or a compound. Actually, an element consists of a number of atoms of the same kind, but a chemical compound consists of atoms of at least two kinds. Countless compounds occurring in Nature can be reproduced in the laboratory, whilst thousands of compounds can be produced artificially that do not occur in Nature.

Oxygen and hydrogen are elements—that is to say nothing but oxygen can be obtained from oxygen, and nothing but hydrogen from hydrogen. Water, on the other hand, is a compound of the two, and by analysis can be resolved into oxygen and hydrogen atoms. This was not discovered until after Cavendish, Volta, Humboldt, Gay-Lussac, Lavoisier, and other scientists had expended years of patient labour. It was Joseph Priestley, the discoverer (in 1774) of oxygen, who in 1781 found that the explosion of oxygen and hydrogen in a closed tube produced water. He thus proved that water was not an element, as had been supposed up to that time, but a compound of the two gases. Oxygen is sixteen times as heavy as hydrogen, atom for atom, and the proportion by weight in water (which is composed of two hydrogen atoms to every one oxygen atom) is 16 of oxygen and 2 of hydrogen or 8 to 1.

Let us now explain how we obtain the chemical formula H_2O for water. When atoms combine to form compounds they always do so in definite proportions by weight that are characteristic of the compound. The atomic weights of each of the 92 elements are known and each, therefore, is placed in its correct position in the table of elements. This commences with No. 1, hydrogen the lightest element (atomic weight 1·008) and runs to No. 92, uranium (atomic weight 238·10). Thus, as the atomic weight of hydrogen is 1, and that of oxygen 16, the symbol H means 1 part by weight of hydrogen and the symbol O means 16 parts by weight of oxygen. The expression of the composition of water by the formula H_2O therefore means that it is composed of hydrogen and oxygen, that 18 parts by weight of the compound are composed of 2 parts by weight of hydrogen and 16 of oxygen.

CONSTITUENTS OF AIR

Air consists of gaseous elements mixed but not combined, each element retaining its peculiar characteristics. Water, consisting as it does of two gaseous elements, displays the properties of neither. We may measure out into a test tube the requisite proportions of the two gases, but they form only an invisible gaseous mixture. This mixture does not possess any of the properties of water, although the tube contains in correct proportion all that is necessary for the production of water. If an electric spark be made to occur in the tube, the gases will disappear and in their place will be found a drop or two

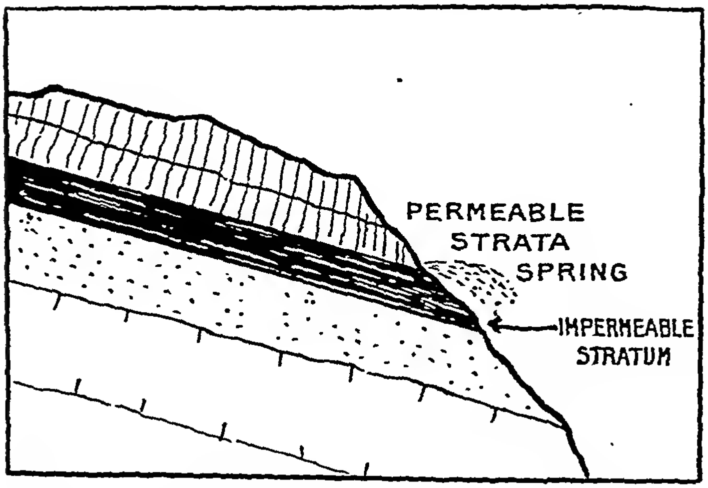


Fig. 1. How a surface spring comes to the surface on the side of a hill. Many of these springs may be seen issuing from the southern face of the North Downs in Kent, Sussex and Surrey.

of water. If desired, this water can be decomposed into the mixture of the two gases as before.

When a compound is resolved into its constituents, the process is called analysis. The opposite process—the building up of a compound from its constituents—is termed synthesis. Synthetic dyes, for instance are those built up in the laboratory, as distinct from substances that are natural dyes. It is interesting to learn that the discovery of the composition of water was made not by analytical processes but by synthetical—that is to say by putting the constituents together in conditions in which they would combine to build up the compound.

THE PROPERTIES OF WATER

Water is colourless, tasteless, and odourless. It is a powerful reflector of light and a bad conductor of heat and electricity. It is totally unlike either of the gases of which it is composed, being neither a supporter of combustion like oxygen, nor combustible like hydrogen. It is, of course, of the greatest importance to mankind, and a glance at any map will show that nearly all important towns and cities are situated on some river. In most cases this arises from the fact that the towns of to-day occupy the same sites as did the settlements of prehistoric man. These always were made near a river, where there was a plentiful supply of fresh water. Tracing back these rivers we find that most of them have their source in a stream or brook, that generally originates in a spring of one kind or another. Let us see how springs originate.

We have already seen that a great amount of the rain that falls percolates into the Earth. Exactly how deep the water percolates depends, of course, on the nature of the ground. Those rocks—such as clay—that refuse to allow water to soak through are said to be impermeable, although sometimes an impermeable rock may allow a quantity of water to pass because it is fissured with cracks. Others—such as limestone and sandstone—are known as permeable, because although apparently hard and durable, they are sufficiently porous to allow water to pass through the interstices, or little spaces, that are left between their individual particles. Although some such rocks may appear to be sufficiently close-grained to withstand the passage of water, they do in fact absorb it, as is often evident from the fact that stone freshly quarried generally holds a quantity of water known as "quarry water".

All this water that is absorbed by the rocks continues to sink through the underlying strata until eventually it reaches an impermeable stratum. At

this point, known as the line of saturation, its further percolation is arrested. It may be that the strata are inclined at an angle—due to earth-movements as already explained—in which case the water that has percolated through from the rocks above will flow along the impervious stratum, endeavouring to escape. When and if this stratum reaches the surface, the water flows out of the rock in the form of a surface spring. This most usually occurs on the side of a hill (Fig. 1), and many of these springs may be seen issuing from the southern face of the North Downs, at the base of the permeable chalk deposits that overlie the impermeable clay.

Should the impervious stratum not reach the surface, the percolating water may form subterranean lakes, often very extensive and perhaps connected one with another by subterranean rivers. Deep down—about 1,600 ft.—under Paris is a river of the purest water, believed to originate at Mont Blanc, and capable of supplying 200,000 gallons a minute if required. Many valleys in the North Downs have their subterranean watercourses, the contents of which are discharged into some river or into the sea. When these deep-seated water supplies are tapped for water for domestic purposes, the wells often have to be driven to great depths before they reach the water.

Below London is a great natural reservoir of water that is tapped by numerous artesian wells. Water from the Chiltern Hills and the North Downs flows to this underground reservoir, formed in a great chalk-bed 600 or 700 ft. thick. The rain that falls on the chalk in these parts percolates through

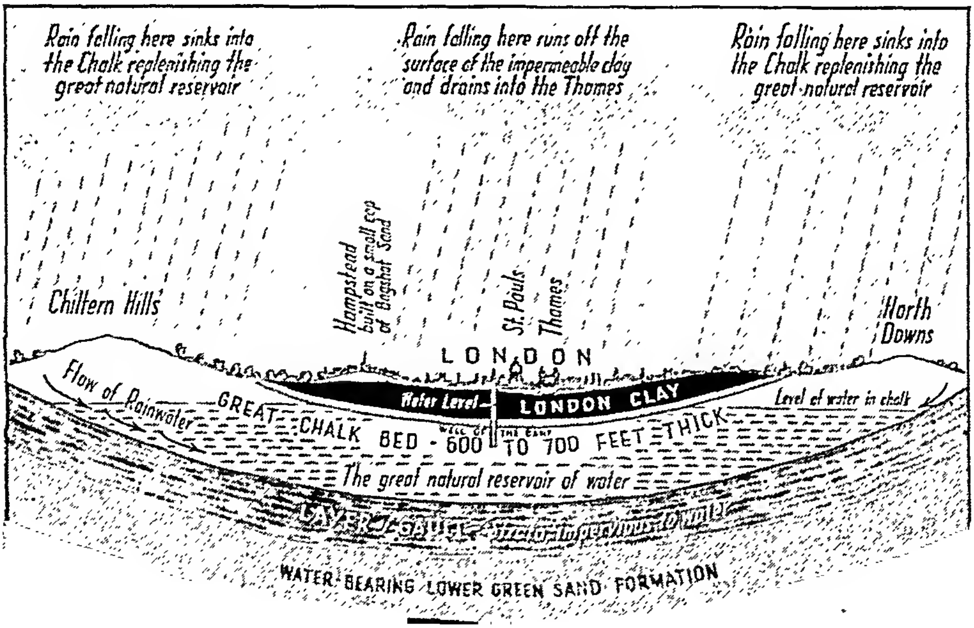


Fig. 2. A sectional drawing of the London area, showing the enormous reservoir of water collected in the chalk-bed. Water from the Chiltern Hills and the North Downs flows to this underground reservoir, formed in a great chalk-bed 600 to 700 ft. thick. The drawing is not to scale.

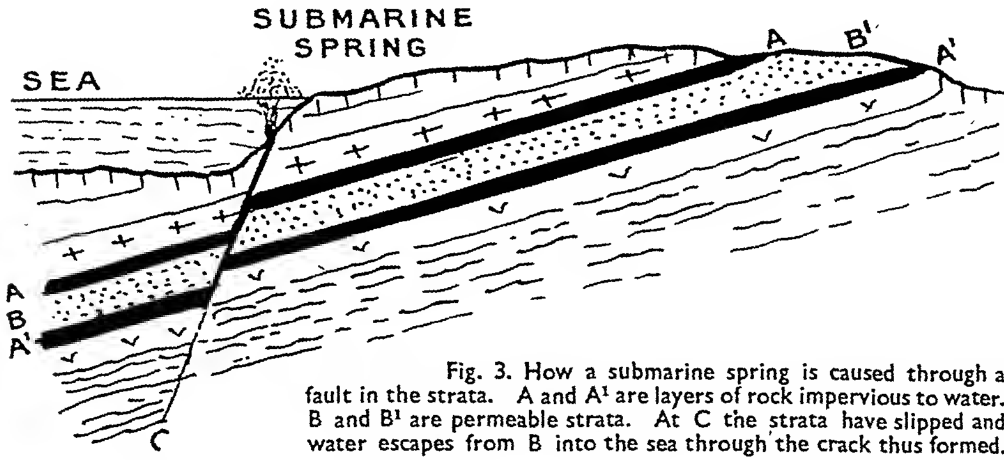


Fig. 3. How a submarine spring is caused through a fault in the strata. A and A¹ are layers of rock impervious to water. B and B¹ are permeable strata. At C the strata have slipped and water escapes from B into the sea through the crack thus formed.

the permeable bed and replenishes the underground supplies. It is prevented from sinking lower than the chalk-bed by an underlying layer of gault strata that is impervious to water (Fig. 2).

Under London itself is a bed of clay that prevents rain that falls on London reaching the chalk, so that the rain runs off the surface of the impermeable clay and drains into the Thames. By sinking artesian wells through the London clay, however, this great natural reservoir can be tapped.

HOW AN ARTESIAN WELL WORKS

The principle of the artesian well is not difficult to understand.

In a liquid that is at rest the pressure is uniform over all points in a horizontal plane, even though the liquid may not extend to the same depth over the containing vessel. This statement may be expressed in another way by saying that a liquid always finds its own level. If a number of glass vessels of various shapes and sizes are connected to a tank, and if liquid is poured through any one of them until the tank is more than filled, the level the liquid attains will be the same in each vessel, even if the tank is tilted at an angle. An important application of this principle is that of the artesian well. A well is sunk through the ground to an underground water supply. Up the well-shaft the water finds its own level (Fig. 2). If this is not at a convenient height, the water is brought the rest of the way to the surface by pumping methods.

Some springs come to the surface beneath the sea, and may be seen around our coasts at low tide (Fig. 3). There is a large spring that comes up in Dover Harbour, and another in the Humber between Barton and Hessle. Near the Gulf of Spezia, fresh water mingles with the salt water. The population of Bahrein in the Persian Gulf depend on the fresh water that they obtain from the sea. Boatmen dive to the sea bed with water-skins at a known spot and bring the supplies ashore. These particular submarine springs probably originate in the hills of Oman, 500 miles distant.

Some springs are intermittent, discharging water for a time and then ceasing. The well-known "Woe Water", or the "Bourne Flow", at Croydon belongs to this class. These springs have discharged irregularly at intervals for many centuries and their activities have been regarded as portents of battles, famines, and plagues. At Giggleswick in Yorkshire is a remarkable ebbing and flowing well in which the

water rises until a stone trough is filled. The trough may then begin to empty at once, or there may be an interval of 15 or 20 seconds before it does so. The process will take between two and three minutes, at the end of which time there will be an interval of from five to nine minutes before the cycle commences again.

At one time it was thought that this well must be connected with the sea and that the tides in some way caused the mysterious ebbing and flowing. The fact is, however, that the phenomenon is caused by a syphon, the principle of which is illustrated in Fig. 4. Two chambers in the hillside act as natural reservoirs and feed the well, water accumulating in one (A) from which the outlet is in the form of a syphon leading to the other chamber (B). When the water in A rises to the level of the bend of the connecting arm it discharges, and the whole of the water in A is syphoned out. The chamber B, being smaller than A, fills rapidly and the water rushes into the trough. From here it flows away under the roadway, to leave the trough empty. As the passage between the two chambers is very narrow some minutes elapse before chamber B is again full enough to supply the well. So far as is known the Giggleswick well is the only one of its kind in the country, although formerly there were similar wells at Tidswell in Derbyshire and at Torbay.

Many rivers have their origin in the water that falls on impermeable strata, where there is no percolation. Here the numerous rills and streams unite, and gathering additional water from tributaries, soon form a river. Other rivers owe their origin to the overflow water from lakes, or to the melting of some glacier, as in the case of the Rhône.

When a river flows over a level plain,

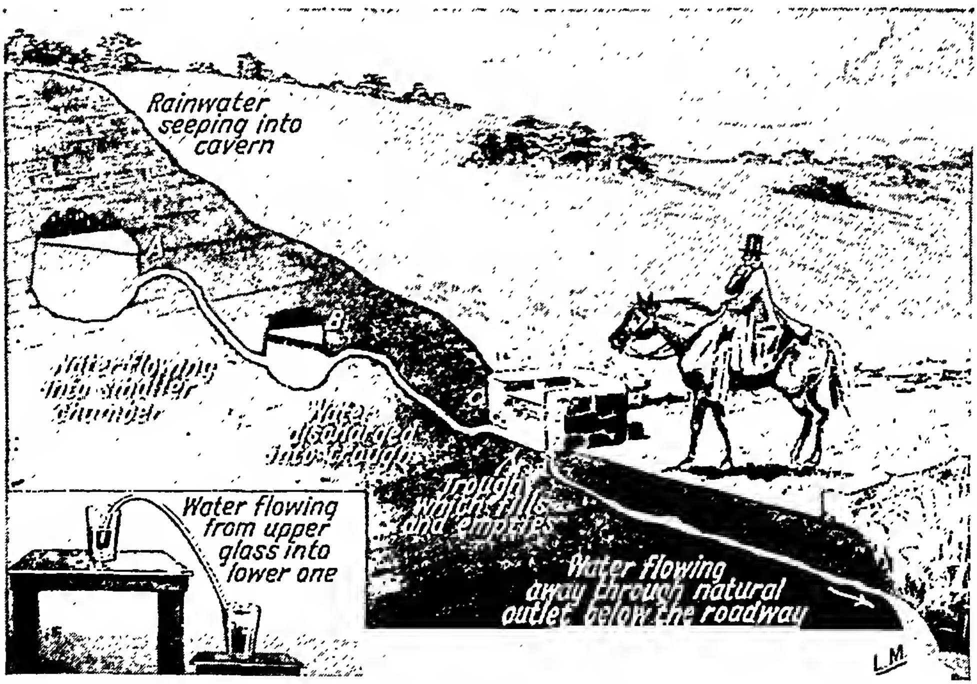


Fig. 4. A theory of how the Ebbing-and-Flowing Well near Settle, in Yorkshire, works.

this together with the country that the river drains, is called the river basin because the configuration roughly resembles a basin with the river flowing along the bottom. The "catchment area" is that which feeds the streams that act as tributaries to the river, the dividing line between one catchment area and another being known as a "watershed". Although this always runs over high ground it is not always the highest ground in the region, for the highest mountains are often more or less isolated from the main range. Rivers flowing from the front of a range of mountains generally rise far behind among the mountains—for example, the Brahmaputra and the Indus rise in the elevated regions north of the Himalayas and not actually in that mighty range through which they flow.

WHAT MAKES A RIVER FLOW

A river flows by virtue of the impetus it receives by its descent from the high land, and this will be sufficient to keep it moving even over level ground. Naturally, when its course is sloping it will have a greater velocity than when the course is over a level plain, so that the velocity of rivers varies according to the gradients of their courses. Actually, even the gradients of swiftly-flowing rivers are not as great as might be supposed. The Danube falls about 10 ft. in the mile, in its higher reaches, but at Vienna the fall is only about 1 ft. in $2\frac{1}{2}$ miles. The Nile has a fall of only about 4 in. to the mile below Cairo, and the Thames 21 in. to the mile. The Amazon falls only $\frac{1}{5}$ in. in a mile over the final 700 miles to the mouth.

The velocity is also affected by the volume of water and by the width of the river, and varies according to the actual position in the river. It is lowest near the bottom and at the sides, where the flow is retarded by friction with the river bed and the banks. It is greatest at about $\frac{1}{3}$ the depth in mid-stream. According to its velocity so does the power of a river vary in the part it plays in the denudation of the land. The greater its velocity, the greater its power to transport material. A river with a velocity of 3 in. per second is capable of carrying fine mud; of 6 in., sand; of 12 in., fine gravel; of 24 in., pebbles, and so on.

TYPES OF RIVERS

The course of a river is largely determined by the character of the country through which it flows. Some rivers, it is true, cut a more or less direct path through solid rock, as in the case of the Colorado river that for 300 miles flows through the Grand Canyon—one of the marvels of the world. Here, through the course of untold ages, the river has worn away a gigantic chasm twelve miles in width and a mile in depth (Fig. 5). But most rivers meander and wind on their courses, diverted in this or that direction by outcrops of hard rock or other natural obstacles. Many rivers have tortuous courses, twisting and turning in an extraordinary manner. The River Jordan, for example, winds so much over a distance of seventy miles between Lake Tiberias and the Dead Sea that the length of its course here is over 200 miles. After a period of time any river will undermine the banks along which it flows (Fig. 6), so that ultimately the weight of the ground above is too much for the bank to support and it falls into the river. Thus at each bend of the river the outer banks are being cut away and in the course of time the valley is cut deeper and deeper.

Then again, the land over which a river flows may impart some particular characteristic to it. The waters of the Salt River in Australia and the Rio

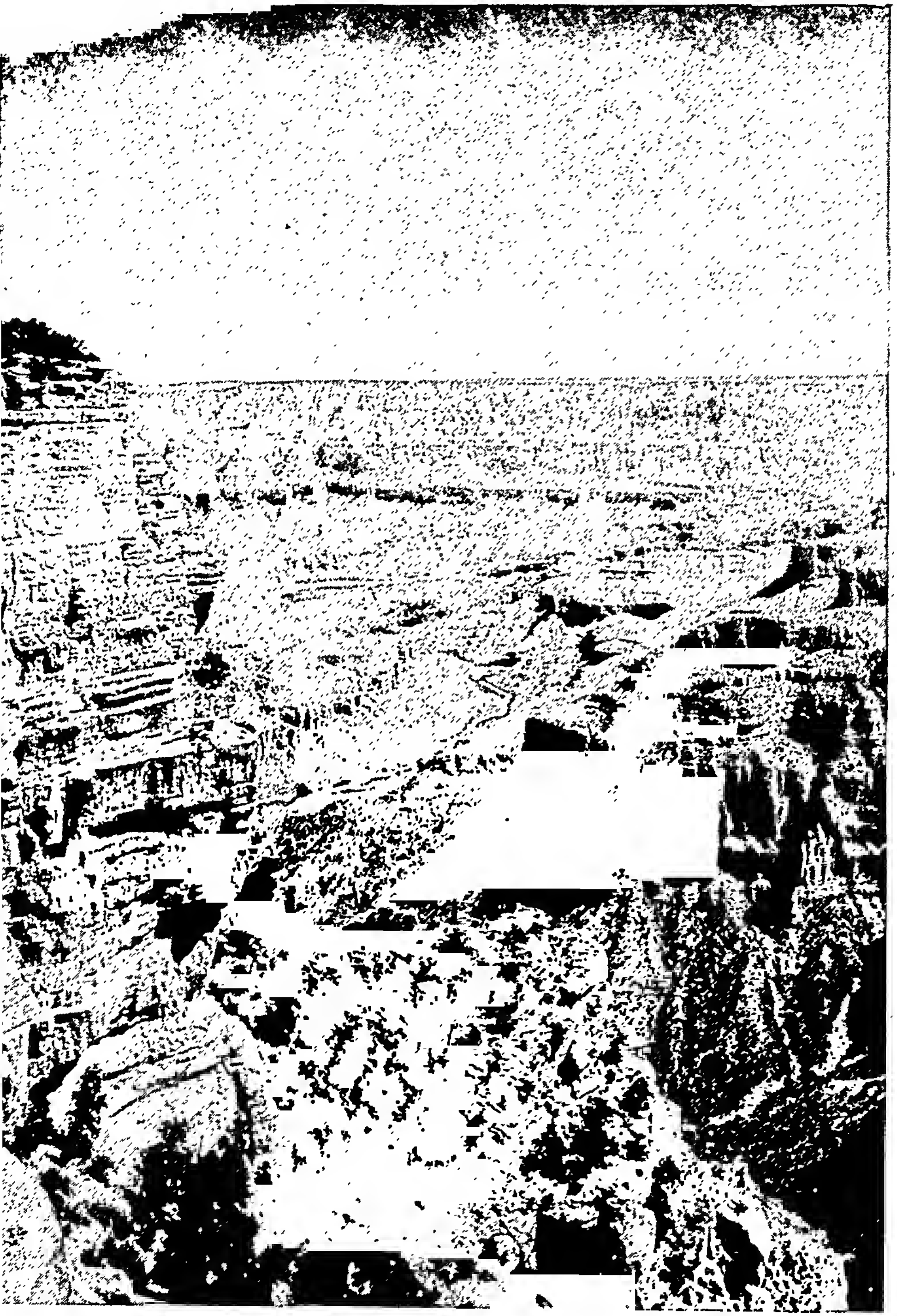


Fig. 5. The Grand Canyon in Arizona, U.S.A., from Cape Royal. The river Colorado has worn away this gigantic chasm, a mile in depth and twelve miles in width.

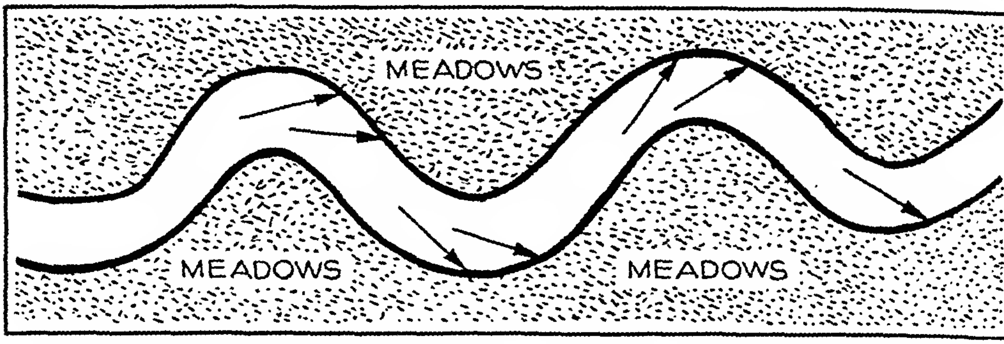


Fig. 6. How a river undermines its banks by continually flowing against them at the bends.

Salado in the Argentine are saline, because they have taken up certain mineral salts from the soil over which they flow. The waters of the Rio de Vinagre of New Granada in Central America have a vinegar-like taste, because of the great quantities of sulphuric acid which they contain.

COLOURED RIVERS

Some rivers are coloured, as in Algeria where one tributary of a river is impregnated with iron and another with gallic acid taken up from peat marshes. As these two ingredients are used in ink-making, it is only natural that when the two tributaries unite the result is a river literally "as black as ink". Of the others, there are several "white" rivers—the White Nile; the Red rivers of the U.S.A.; the Hwang Ho, or Yellow River of China, the "Yellow Tiber" and finally, the Blue Danube. Most of these "coloured rivers" owe their colour-reputation to matter held in suspension by the waters, coupled perhaps with a little imagination on the part of those who so named them!

Some rivers, such as the Elbe—are notable for their shallowness, others for their great depth, as the Viamala, which from Scahms to Thuses is 1,600 ft. in depth; others—as the Plate river—for their great width; and others again for their length. The longest river is the Mississippi, which, with the Missouri—the two are usually regarded as one—extends for 4,200 miles; the Amazon is 4,095 miles long. The longest rivers in Asia are China's Yangtse-Kiang and Siberia's Yenisei, both 3,200 miles in length. Africa's representatives are the Nile, 3,500 miles; followed by the Congo, 3,000 miles. The best Europe can do is the Volga, 2,300 miles; followed by the Danube, 1,750 miles. The Thames, one of the most important rivers of the world, is a mere 210 miles in length.

A waterfall is caused by a stream or a river plunging over a step in the rock-formation or over a precipice. It is generally due to a sudden alteration in the geological formation of a river bed, as when it changes from a hard to a soft rock, the soft rock being worn away by the falling water, so giving the fall an increasing depth as time goes on. Such is the case with most of the falls in Switzerland, where the rivers flow over a bed of hard limestone. This has resisted the eroding action of the water, forming ledges over which the waters leap into basins or gorges cut in the softer rock below.

It is because the hard rocks, such as granite, are generally near the surface in mountainous districts that waterfalls are more common in these regions. Where the harder rocks have been subjected to upheaval there are more frequently changes between hard and

soft strata, so that in nearly all places where rivers cut through mountain ranges there will be waterfalls. We find them particularly on the rivers that cut through the Rockies and the Andes, and on those African rivers that flow from the interior to the ocean and have to cut through mountain ranges that lie in their paths. On the other hand, waterfalls are seldom found when rivers run parallel to mountain ranges, nor in rivers that flow over prairies or plains. If there are any on such rivers it is because veins of granite, limestone, or some other hard rock, attempt to bar their passage. No waterfalls are found, for example, on the Amur or on the Yangtse-Kiang, which is navigable for 1,700 miles, but in Southern China where the Si-kiang and the Song-ka have to cross the mountain ranges, waterfalls are numerous.

Some waterfalls are more picturesque than others. This depends largely on the geological formation of the locality in which they are situated. Some are long thin "pipes" of water which by the time they reach the end of their journey are little more than columns of attenuated spray, so great is the height from which they fall. On the other hand, there are stupendous falls where millions of gallons of water pour over vertical precipices every minute. Other falls descend step by step, over a considerable distance, forming a cataract rather than a waterfall.

Waterfalls are generally very destructive to the river-bed and play an important part in the denudation of the land. This is particularly the case if the bed of the river is a hard rock lying in the softer shales or sandstones. Rushing over the ledge, the water dashes with considerable force against the softer rocks beneath, wearing them away and undermining the hard stratum above.

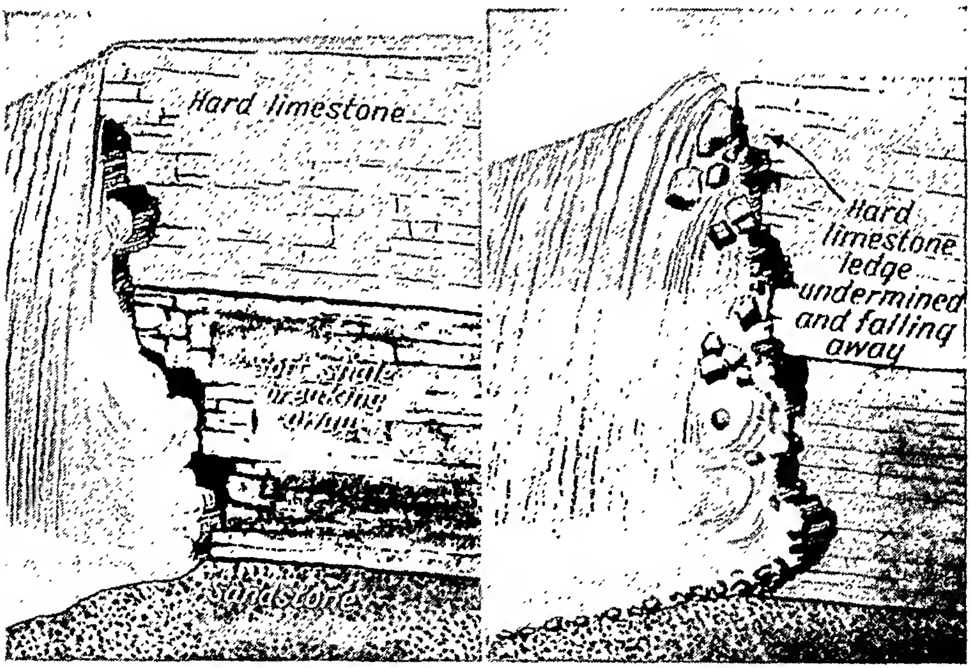


Fig. 7. How waterfalls recede. The water cuts away the soft underlying rock so that the harder strata on top are undermined and, being unable alone to support the great weight of the water, finally break away and fall into the river below.

Unable alone to support the weight of the water, this breaks away and falls into the river below (Fig. 7).

Such is the case with the Niagara Falls, perhaps the most famous, but by no means the largest, waterfall in the world. These falls are caused by the passes over the Canadian Falls, where it has excavated a basin as deep as the Fall is high. Although the river has cut a deep chasm in the shale, it has not been able to make any impression on the hard limestone, although the water at the bottom of the fall is undermining

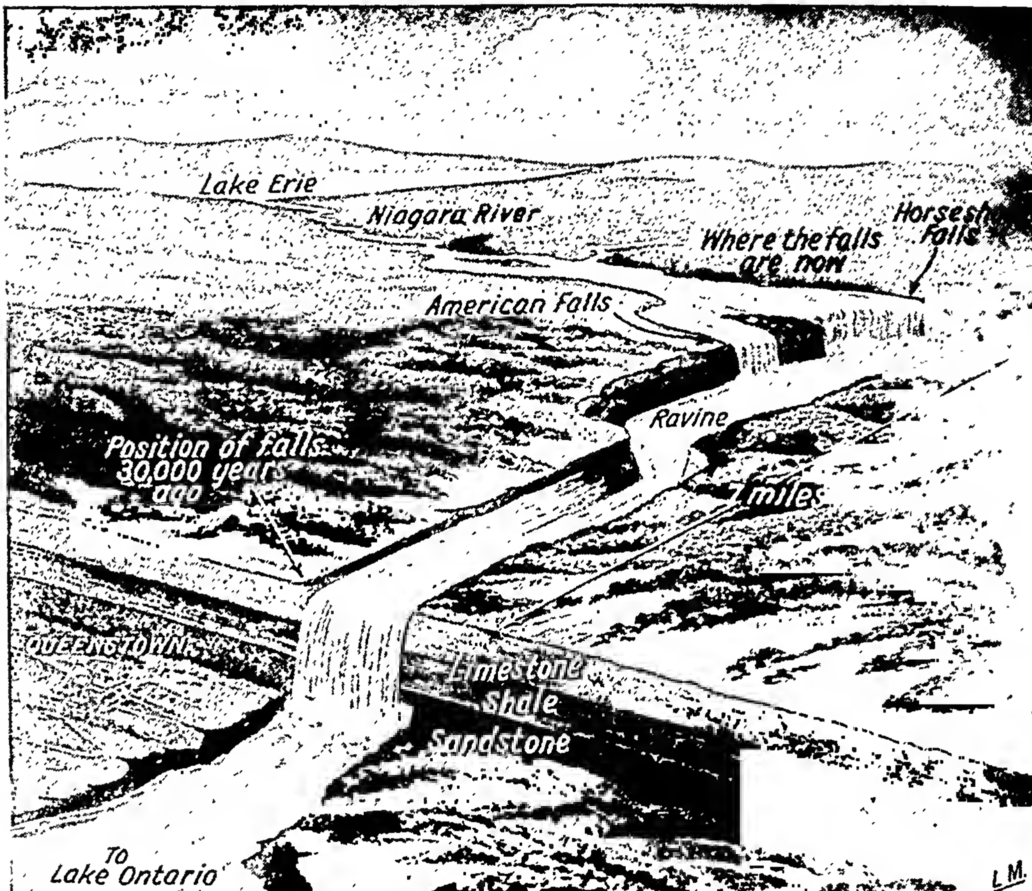


Fig. 8. Where Niagara Falls were 30,000 years ago. Since that distant time the Falls have receded seven miles up the gorge. Sometime in some future age the Falls will reach Lake Erie.

overflow from Lake Erie, which forms the Niagara River. It plunges over a ledge of hard limestone, resting on a bed of soft shale. The river at this point is divided into two by Goat Island, forming the American and Canadian Falls—1,060 ft. in width and 162 ft. in height, and 3,150 ft. in width and 155 ft. in height, respectively. About 94 per cent. of the total water of the river the softer strata below in the manner already described. This has resulted in the Falls moving slowly backwards for thousands of years. This recession is believed to have brought the Falls to their present position from the end of the gorge, some seven miles nearer the shore of Lake Ontario where Queenstown now stands (Fig. 8). It is estimated that since the Falls were discovered

(in 1678) by the Jesuit missionary Father Hennepin, they have receded about 1,000 ft. nearer to Lake Erie.

Four of the largest waterfalls in the world are situated in South America. Strange to say only a few white men have seen them.

WORLD'S LARGEST WATERFALLS

The Kaieteur Falls, on the Potaro river in the wilds of British Guiana, were discovered in 1870. The river flows over a sandstone and conglomerate tableland into the valley 822 ft. below, so that the Falls (Fig. 9), are about five times the height of Niagara.

The Paulo Affonso Falls in Bahia, Brazil, divide into four and plunge into a gulf some 300 ft. below. Five miles above the Falls the river is a mile and a quarter in width, but it suddenly contracts to a width of 56 ft. so that an enormous volume of water is hurled into the abyss with tremendous force.

The Iguassú Falls, partly in Argentine and partly in Brazil, are situated in the heart of virgin forest beyond Asuncion. Here the Curityba river descends from the great Brazilian plateau to the lower levels, the Falls being about 1,500 ft. wider than Niagara and about 200 ft. in height.

The fourth of these great waterfalls of the world are the Guayra Falls on the Paraná river, which lower down becomes La Plata. Their height is 373 ft. and there are eighteen separate falls, the river descending by enormous steps that form a unique series of cascades and gorges, in which 20-ft. waves are formed and great clouds of spray that can be seen for miles around. The flow of water is over 500,000 cubic ft. per second—more than double that of Niagara. If the Falls could be harnessed they would provide the greatest source of power in the world.

At the mouth of some rivers the material brought down by the waters forms deltas. They are so called because the shape assumed by this deposited material is roughly that of an equilateral triangle thus resembling the Greek letter *delta*, the capital sign for which is Δ. Deltas form as the speed of the river slackens, this slackening being due to the fall of the bed decreasing as it approaches the sea. The tendency then is for much of the matter in suspension to be deposited—first the gravel and the sand, then the finer materials, leaving only the finest particles; and even they eventually are deposited. If the sea into which the river discharges is not disturbed by currents, and if there is no tidal action, in time the sediment accumulates and forms a fan-shaped deposit. Obviously this can only occur if the materials are deposited at a greater rate than that at which they are carried away by the movements they encounter in the sea. In time this sediment may silt up the mouth of the river so that a new channel, or channels, must be formed. These again form secondary deltas, the deposits constantly accumulating and forming new alluvial land at the mouth of the river.

DELTAS AND THEIR FORMATION

The nature of this delta land varies according to local conditions and the nature of the material brought down. The land may be swampy, as in the case of the great Indian rivers the Ganges and the Brahmaputra, in the marshes of which grow mangroves and nipa palms. On the other hand, the land may be dry and habitable, as in the case of Holland, which covers an old delta formed by the Rhine and the other rivers that now flow through the country.

Deltas are often valuable additions to existing land, and in the course of time they may cause great changes, as in the case of the River Po. In times

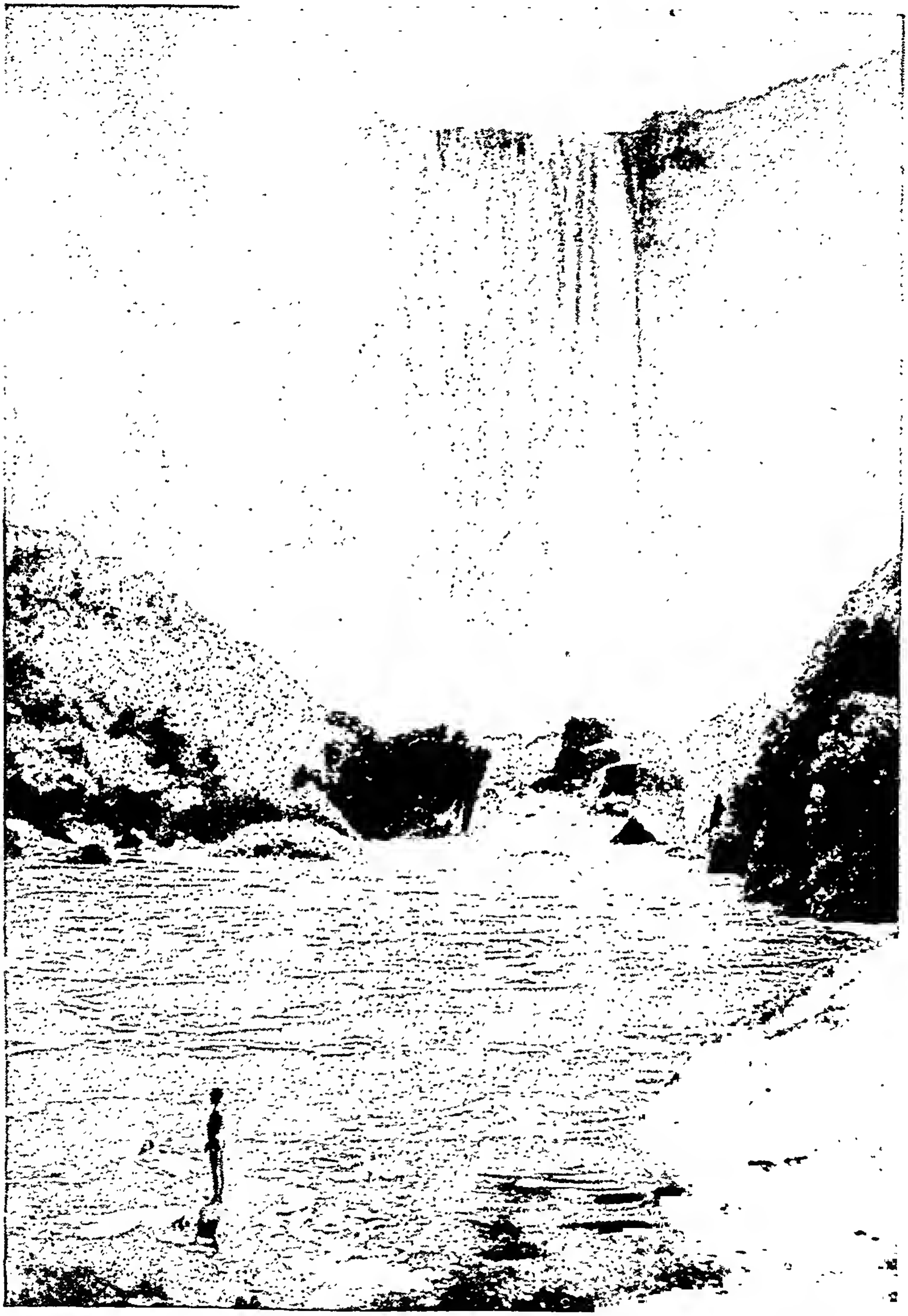


Fig. 9. The wonderful Kaietur Falls on the Potaro river in British Guiana. The falls are four times the height of Niagara and have a drop of 822 feet.

gone by the town of Adria was a port on the Adriatic, but owing to the accumulation of deposits at the mouth of the river, it is now 20 miles inland. Sea shells have been found in the valley of the Euphrates near Babylon, although the site of Babylon is now some 400 miles distant from the river's mouth. The Plain of Babylon has been extended by silting up at least from this point, and the rivers of this valley now discharge their waters into the Persian Gulf some 350 miles further seaward than in 10,000 B.C.

There is an enormous delta in Lower Egypt produced by the Nile, which branches into two main streams some 120 miles above the mouth. The Nile delta is enclosed in a triangular area with Cairo, Rosetta, and Damietta at its corners, and it is clear that the area extending from Cairo to the sea, a distance of over 100 miles, has been brought down by the Nile, which at one time entered the Mediterranean at Cairo. From borings that have been made it is evident that the alluvial deposits extend to a depth of 120 ft. or more. In the time of Herodotus, Memphis was on the shore of the sea, but to-day it is 100 miles inland. The land between is composed of the disintegrated rocks from the Abyssinian mountains, brought down by the Nile and the Atbara.

SILTING UP OF KENTISH MARSHES

In Britain we have an illustration of the changes that may be brought about in a similar manner, for there has been much silting up in the Kentish marshes. In Roman times there was a channel wide enough to admit the Roman fleet between the Isle of Thanet and the coast of Kent, but this channel no longer exists, the so-called Island being now actually part of the mainland, joined to it by a tract of alluvial land.

The Colorado river carries enormous quantities of solid matter to the sea—in a year it carries sufficient material to cover 105,000 acres to the depth of a foot—and an enormous delta has formed in the Gulf of California. Year by year this delta is increasing in size as the great quantities of silt spread out into the Gulf.

The delta of the Mississippi covers an area of 12,300 square miles, the river depositing some 6,000,000,000 cubic ft. of material every year. A well sunk in the Missippi delta went down to a depth of 620 ft. without reaching the limit of the alluvial deposits. The delta of the Mississippi forms a huge tract of swampy land, through which flow numerous streams.

WORLD'S LARGEST DELTA

The largest delta in the world is the Sunderbunds, formed by the Brahmaputra and the Ganges, both of which rivers flow down from the Himalayas. They form a delta that has an area equal to that of Eire, and is increased each year by large quantities of mud. Up one of the branches of this delta, at the mouth of the Hooghly river, on which Calcutta stands, a great river-bore sweeps at certain times of the year. It is first seen at Buffalo Point, advancing at the rate of 20 miles an hour, and by the time it has reached Buj, 30 miles further up, it has a crest 4 ft. in height. At Chundurah, 17 miles above Calcutta and nearly 70 miles from its commencement, the bore reaches a maximum height of 6 or 7 ft. These river bores are caused by tidal water meeting the swiftly-flowing waters of a river in a comparatively narrow channel so that the incoming water is "piled up", as it were, into a great wave that sweeps up the river.

Most rivers in Britain have too rapid a fall, or are not large enough, to form deltas. As most of our large rivers are

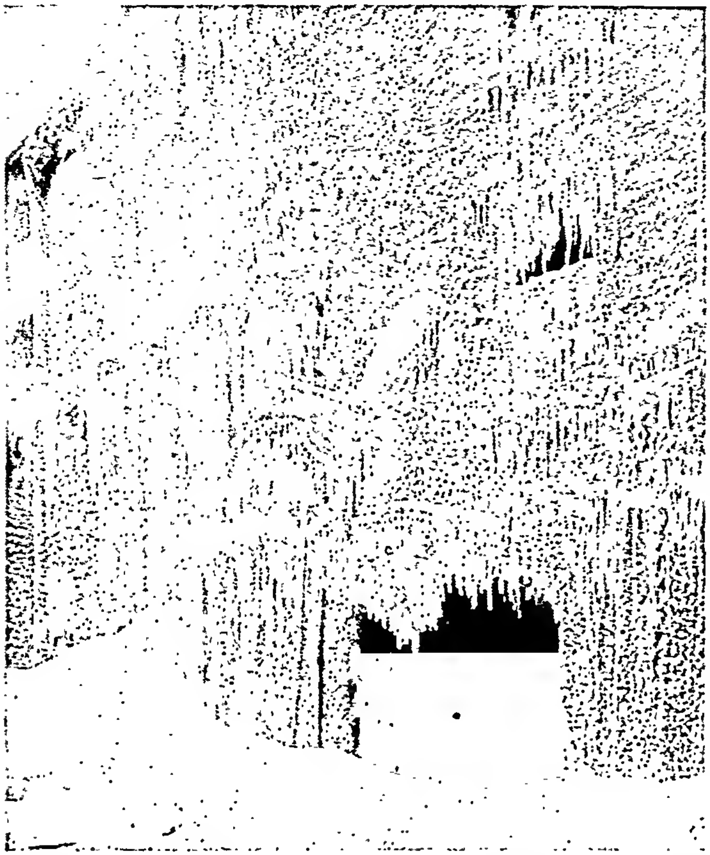


Fig. 10. The frost during a fire in Toronto was so severe that the water from the hoses froze as it fell on this burning building.

tidal, the sediment is swept away by the regular tidal flows, the ebb tide coupled with the flow of the river taking the sediment away. In some cases, however, the sediment is piled up into a "Bar"; and when the piling up occurs further out to sea the deposit forms "shoals". The River Mersey has a Bar, and it is necessary continually to have dredgers at work to keep a clear passage at the mouth of the river, the danger point being marked by the Bar Lightship. The Thames is an example of a river-mouth where shoals form in the estuary, but there is always sufficient scouring action by the tides to keep the channel open to navigation, despite the 14,000,000 cubic ft. of solid matter that is carried down to the sea every year.

Ice, the solid form of water, consists of large numbers of minute but definite forms known as crystals. Although much has been learned about crystals, particularly by means of X-rays, the actual process of crystallization remains one of the mysteries that science has yet to solve. It is apparently a peculiar ordering of cohesion and is an active interference with the operation of the molecular force of simple cohesion. Crystals have a law of form, each one having a particular shape, the angles of which can be measured, and we shall refer to the matter again in connection with snow-flakes.

Water expands when heated and contracts when cooled at and above a temperature of 39°.2 F. Below that temperature an opposite action takes place and it expands until it reaches 32°F., when ice is formed. The expansion of water when freezing is, of course, the cause of burst waterpipes, but owing to the water in them being solidified the actual burst is not generally detected until a thaw sets in and the ice in the pipes is converted back to the water that escapes through the "burst".

FORMATION OF ICE

If water is under pressure a lower temperature is necessary to solidify it. Should the pressure be suddenly removed, the water immediately solidifies and expands with tremendous force.

Because the water has so expanded before freezing the resulting ice is of less density than water, so that a solid block of ice weighs less than an equal bulk of water. If we have a volume of water weighing, say, 1,000 lb., ice of equal volume will weigh only 917 lb. This is the reason that ice floats in water with about $\frac{8}{9}$ of its volume below the surface. Consequently, ice-bergs that appear large, towering on the horizon, are in reality much larger, since only about one-ninth of their total extent is seen above the sea.

EFFECT OF SEVERE FROST

When a frost is severe, ice forms very quickly—on occasions, indeed, water will freeze as it leaves the nozzle of a fire hose and on a building that is burning (Fig. 10). On occasions of severe frost rivers are completely frozen over—the St. Lawrence, for instance, is closed to shipping for several months each year. It is not often that the large rivers in Britain are frozen, but occasionally this does happen. A few centuries ago whenever the Thames was so frozen, "Frost Fairs" were held, and swings, coconut shies and other fairground delights, were erected on the ice. At night huge fires provided light for skating, skittles, and other forms of amusement.

In the winter of 1683 there was a celebrated Frost Fair, when the frost lasted for two months and the river was frozen to such a degree that another city seemed to have been created on it. Streets of booths were erected and occupied as shops by all kinds of tradespeople, and even a printing press was set up on the ice. Coaches plied on the ice from Westminster to the Temple, and bull-baiting and horse racing were the orders of the day—and night, too! The last Frost Fair was held in 1814; since then something seems to have happened to the weather, for the frosts have not been sufficiently severe to enable the Fair to be held.

Ice has many curious properties, not the least of which is that it is very plastic under pressure but not under tension, for it cannot be drawn out into filaments. In the form of a glacier it flows down the valleys, and although travelling comparatively slowly it continually moves at a uniform rate which depends on the usual factors that govern the motion of a viscous mass.

It also has the peculiar property called "regelation", owing to which two pieces of ice pressed together will freeze again to make a solid piece. This property may be demonstrated by placing a block of ice on two supports and suspending a heavy weight on a wire that passes over the block of ice. The weight pulls on the wire so that it gradually cuts its way through the ice, the two pieces produced becoming united again above the wire. Thus, after a time, when the wire has cut half way through the block, it appears as though the wire had originally been frozen in the ice (Fig. 11).

DOES SALT WATER FREEZE?

Some people think that salt water is not subjected to the action of frost and that therefore the sea never freezes.

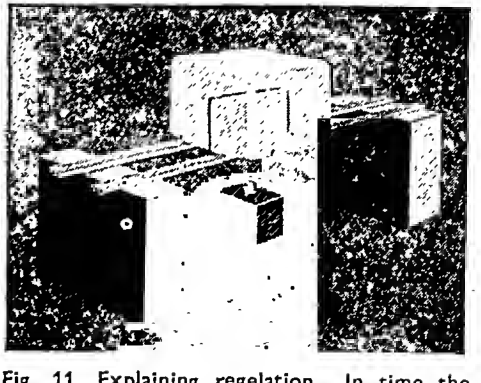


Fig. 11. Explaining regelation. In time the wire will be pulled right through the block of ice but it will not divide it in two.

We need not even ask such people to take a trip to the Arctic or Antarctic circles to dispose of this idea, for sometimes during a severe frost the sea water round our own coasts may be seen frozen, as at Southport in 1936. Salt water will freeze at a temperature of from 26·7° to 31° F., according to the degree of saltness of the water. In the Polar Seas ice spicules or needles form in water that is freezing. These notched blades of transparent ice increase rapidly in number until they form a layer over the whole surface, this layer being known as "bay ice" because it forms more easily in sheltered bays. This bay ice does not form a solid sheet but is quite fluid, making the water "gluey" so that it is difficult for a boat to move through it. As the freezing continues the effect becomes increased, and waves that previously could distinctly be seen in the ice become less pronounced until in due time the sea is completely frozen over with this first thin covering. At first it is black and more or less plastic, but later it changes to white and becomes a brittle mass that completely covers the sea, when it is known as "field ice".

In its first year, polar ice cannot exceed 7 ft. in thickness, unless it is piled up by the wind and waves. In the second year only about 3 ft. can be added, the growth being more rapid when first formed and becoming slower as the thickness increases. Despite statements that the thickness of polar ice is sometimes 18 ft. or more, the general experience seems to be that its average thickness is about 8 ft. except in the case of ice-formations that are due to piling up, when the ice may be of any thickness from 40 to 1,000 ft.

Of all the wonderful formations displayed by Nature there can be none more marvellous or mysterious than the tiny snowflake. Yet this feather-like accumulation of crystals can do tremendous damage and cause great loss of life and property—it can even cause disaster to an army, as Napoleon learned to his cost at Moscow. Nearly every winter, snow causes dislocation of road transport and can involve the Cleansing Departments of our great cities in considerable expense. For instance, the falls of December 1938 and January 1939 involved the City of Leeds in an expenditure of some £10,000 (equal to a penny on the rates) for additional labour to clear the streets of snow. Some 36 snow ploughs were in use, and a reserve of 12,500 tons of rock salt and yellow sand was held in readiness for the emergency. The staff to deal with the clearance comprised 240 casual snow-shifters, 140 regular men from the Highways Department and 350 from the Cleansing Department with over 130 lorries.

MODERN SNOW CLEARANCE

To-day, speed is the secret of modern snow-shifting, the problem being altogether different from that of pre-war days, when heavy vehicles capable of turning snow into slush were few and far between. If not cleared away from the streets of our cities and towns the snow may lie about for a long time, if circumstances permit. For instance after the great storm of 1881, over London, snow was carted to Finsbury-circus, where it was left in great piles, and these did not melt until the following June.

We have already seen that the atmosphere contains a large amount of water vapour. When this vapour freezes it forms clear transparent crystals, each individual crystal so small as to be invisible. These crystals form a nucleus that falls through the air, is caught by rising currents, and falls again, the process being repeated again and again. Meeting ever-changing currents of air and varying conditions of moisture-

laden atmosphere, the crystals develop, gathering together in "families" of perhaps a hundred or more, and slowly sinking to Earth as their weight increases.

Snow flakes are of various sizes and may measure from over an inch in diameter down to as little as $\frac{1}{14}$ in. or so. Their size depends on the atmospheric conditions under which they are formed. The largest ones are formed at temperatures of nearly 32° F. and the smaller ones at a lower temperature and generally in the higher atmosphere at heights of perhaps 8 or 10 miles or more. The crystals are arranged about a centre at an angle of either 60° or 120° and they are invariably either six-pointed stars or extremely thin plates of hexagonal shape. We find this same shape in the cells of the bee and wasp, in petals of flowers, and in many other natural formations. It is one of the marvels of Nature that it should be adopted since, of all the polygons inscribed in a circle,

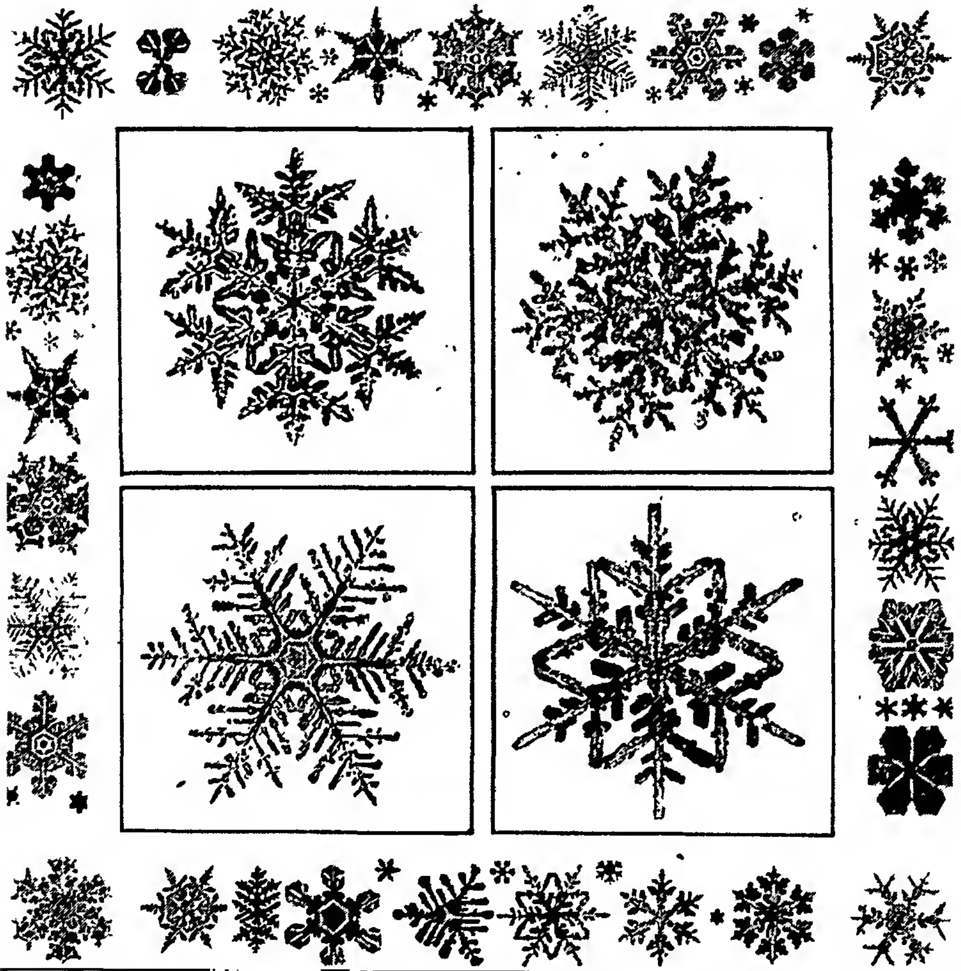


Fig. 12. Some of the innumerable forms taken by snowflakes, arranged in a pattern. Some of the flakes here are duplicates, but these are merely arranged thus to form a design, for out of the countless thousands examined, no two snowflakes have ever been found to be alike. They are always six-pointed stars or thin plates of hexagonal shape with the crystals arranged about the centre at angles of either 60° or 120° We find this same shape in the cells of the bee.

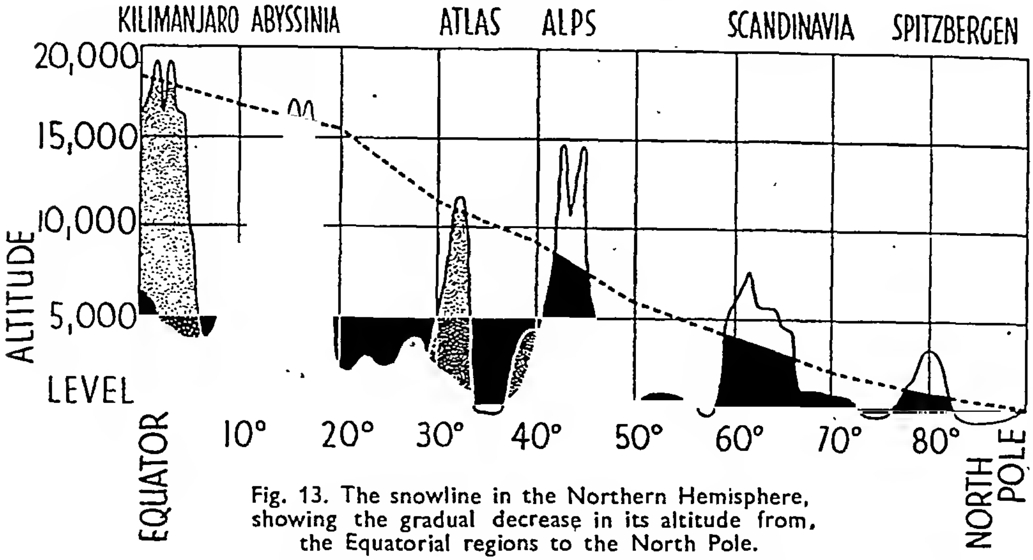


Fig. 13. The snowline in the Northern Hemisphere, showing the gradual decrease in its altitude from, the Equatorial regions to the North Pole.

the hexagon is the only form in which the sides are equal to the radius of the circle, thus enabling the maximum space to be enclosed with the minimum of material. From the nucleus of the six-pointed stars, or pyramids, secondary rays branch off at the same angle as the parent rays, each part of the general pattern being repeated six times around the nucleus. Prolonged study has been made of snowflakes over many years and no two exactly alike have yet been seen. They exhibit the most beautiful forms and such unique patterns that they have often been used as a basis for designs by decorators, jewellers, and other craftsmen (Fig. 12).

STRUCTURE OF SNOW

Actually, snow is colourless, being but frozen water. Its apparent brilliant whiteness is due to the reflection and refraction of light from the numerous surfaces of the large number of crystals. Its opaqueness is due to the presence of air in the snowflakes, without which they would be transparent like ice and other crystalised bodies. We have already mentioned coloured rain, and similarly we find several records of coloured snow. Darwin tells us that during his passage through the Cordilleras (in 1835) the footsteps of the mules were stained red as if their hoofs had been covered with blood. At first Darwin supposed that the colour was due to dust blown from the surrounding mountains of red porphyry, but later found that there was another explanation. As with red rain, red snow may be due to the presence of countless minute plants or *algæ*. In this case they are known as *Protococci nivales*. These microscopic spheres or colourless cases measure less than ·001 in. in diameter. They are so prolific that an Arctic or Alpine landscape has been changed from white to red overnight. Nansen saw drifts of rose-coloured snow, caused in this case by similar minute red *algæ*, *Spærellæ nivales*. He also mentions yellowish-green patches of snow, due to the presence of another species of *algæ*.

Snow cannot fall at places where the general temperature of the atmosphere is never at freezing point, for it would be melted before it reaches the ground. For this reason snow has never fallen at Buenos Aires, or at most places up to 30° N. of the equator and within a

somewhat wider limit to the south of the Equator. The lowest latitude at sea level in the Northern Hemisphere at which snow has been seen is Canton, (Lat. 23°) but in the Southern Hemisphere it has been known to fall at Sydney (Lat. 34°).

SNOW ON THE EQUATOR

There are, however, snow-covered mountains almost *on* the equator, as, for example, Mount Kenya. Mount Kilimanjaro, which rises to a height of 19,400 ft. only 3° from the equator, has a perpetual snow cap. The volcano Chimborazo in South America also has snow. The elevation at which mountains are covered with perpetual snow is called the snow-line (Fig. 13). The upper snow-line is the altitude above which the temperature never is high enough to permit all the snow to melt, and the lower snow-line that at which the temperature is high enough to allow most of the snow to melt in summer, but where snow may be found all the year round in sheltered spots. In the case of Ben Nevis, for instance, the summit is below the line of perpetual snow but above the lower snow-line. In the Southern Hemisphere the snow line reaches sea-level in lower latitudes than in the Northern Hemisphere.

The position of the snow-line depends on variable causes such as the state of the summits, the comparative altitude and physical features of the surrounding country—for instance the particular exposure to which the mountain is subjected—and so on. It is also modified by the amount of snow that falls, for should large quantities fall in winter it requires a greater length of time to melt away completely than is the case if only a small quantity falls. In the Himalayas, for example, the snow line varies from 16,600 ft. to 19,000 ft. and is 2,000 ft. higher on the northern side of the range than on the southern, despite that the latter is nearer the equator. This is accounted for by the fact that the winds blowing on the south side come from the Indian Ocean and are heavily charged with moisture. This is deposited on the southern side as snow, the falls being heavier here than on the northern slopes. On the other hand, the northern side is subjected to hot dry winds that blow across the plains of Tibet, raising the height of the snow-line on that side in comparison with the southern side.

As a general rule, the altitude of the snow-line naturally decreases from the equator to the Poles. At the equator the snow-line is at a height of about 3 miles (16,600 ft.) above sea level; in Lat. 12° N., on the mountains of Abyssinia, it is 14,000 ft.; at the Atlas Mountains south of the Mediterranean, 11,500 ft.; in the Alps, 9,000 ft.; in Scandinavia, 6,800 ft.; and at Spitzbergen, only 1,500 ft. In the Polar regions there is, of course, perpetual ice and snow at sea level.

THE "ABOMINABLE SNOWMAN"

In the perpetual snows of the Himalayas have been seen footprints that furnish one of the great mysteries of science. The natives believe that they are caused by a creature that is half-man and half-beast, and which is known as the Abominable Snowman. This creature has not so far been seen by any European. Yet there is a strong belief in these Mi-go or Mirka—as they are called by the superstitious natives of Nepal and Tibet—and sufficient indirect evidence has been gathered by European travellers and mountaineers to warrant an expedition to investigate the mystery.

The legend of the Abominable Snowmen extends for hundreds of miles through Nepal, Tibet, Sikkim and Bhutan, and the descriptions given by

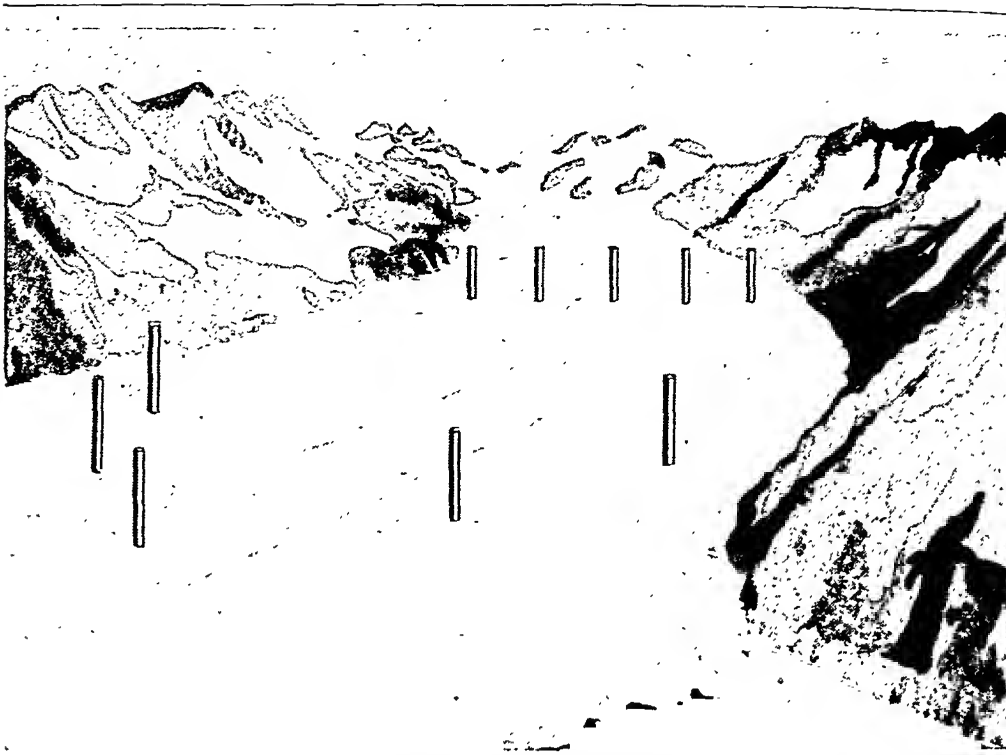


Fig. 14. Showing how the centre of a glacier moves more quickly than the sides. After a time a row of stakes originally driven in a straight line would become curved for the centre stakes would move more quickly than the outside ones because the sides of the glacier are retarded by friction.

the natives of these countries are strangely alike. There seems no doubt but that the Snowman is a monstrous biped, white-skinned and covered with black hair. According to the natives, the larger examples devour yaks which they disable by ham-stringing. Some of the Sherpas of Nepal and Bhutias of Tibet swear to having been chased by these creatures, and lurid pictures of them are to be found in many Tibetan monasteries.

European mountaineers have seen strange tracks in the snow far above the permanent snow-line. Mr. H. W. Tilman, the leader of the 1938 Mount Everest Expedition, has described some remarkable tracks on a snowfield in the Karakorams. They consisted of a line of round indentations the size of soup plates and could not be attributed to otters, birds, or any of the other creatures that were suggested as being the cause of them. Strange tracks have been observed by members of expeditions to Kinchinjunga and other peaks. Not long ago, an English lady, Miss Macdonald of Kalimpong, was crossing a high pass into Tibet when she was started by a terrific roar that shook the ground and was totally unlike the roar of any creature she had heard before. Perhaps the expedition that is going out to investigate these strange tracks will succeed in solving the mystery.

WHAT CAUSES GLACIERS?

Although the temperature of a high mountain is raised during the day, it drops very considerably at night. On mountains there is a much greater difference between day and night temperatures than elsewhere. When more snow falls than can be melted

during the warmth of the day there is perpetual snow. Here the alternate thawing and freezing of the snow, coupled with the constant addition of fresh snow above, causes the lower layers to be compressed into a solid mass. This becomes stratified, the different layers being divided by "dirt-lines", each indicating the previous year's snow on which the wind has deposited dust, leaves, etc. This granular mass is known as *névé* and although not actual ice it forms the beginning of a glacier, or river of ice. With an increasing weight pressing from behind, the mass commences to creep down the mountain, ultimately to form a glacier that may extend for hundreds of miles before it finally enters some lake, or reaches the sea, where it melts.

Glaciers move slowly, rate of travel depending on the amount of pressure exerted on them by the snowfields above and on the gradient of the mountain. The width of the valleys through which they pass also affects their rate of travel, for a narrow valley contracts the glacier and retards its progress. As in the case of a river, the centre parts of a glacier travel more quickly than the sides, being retarded by friction with the sides of the valley (Fig. 14). For the same reason the top part moves more quickly than the bottom, which is in contact with the bed of the valley. In summer the movement is speeded up when some of the ice melts, and the water flowing through cracks in the glacier lubricates the bed over which it is travelling, so tending to reduce the friction. Glacier ice being a viscous body, behaves as treacle or pitch does when flowing down an incline, and so is able to adapt itself to the windings of the valley down which it flows. The average velocity of the Alpine glaciers is from about 5 to 12 in. a day, or 150 to

Fig. 15. The Grosser Aletsch Glacier in the Bernese Oberland, the largest in Switzerland, is 12 miles long and nearly 6,000 ft. broad. Note the medial moraine.

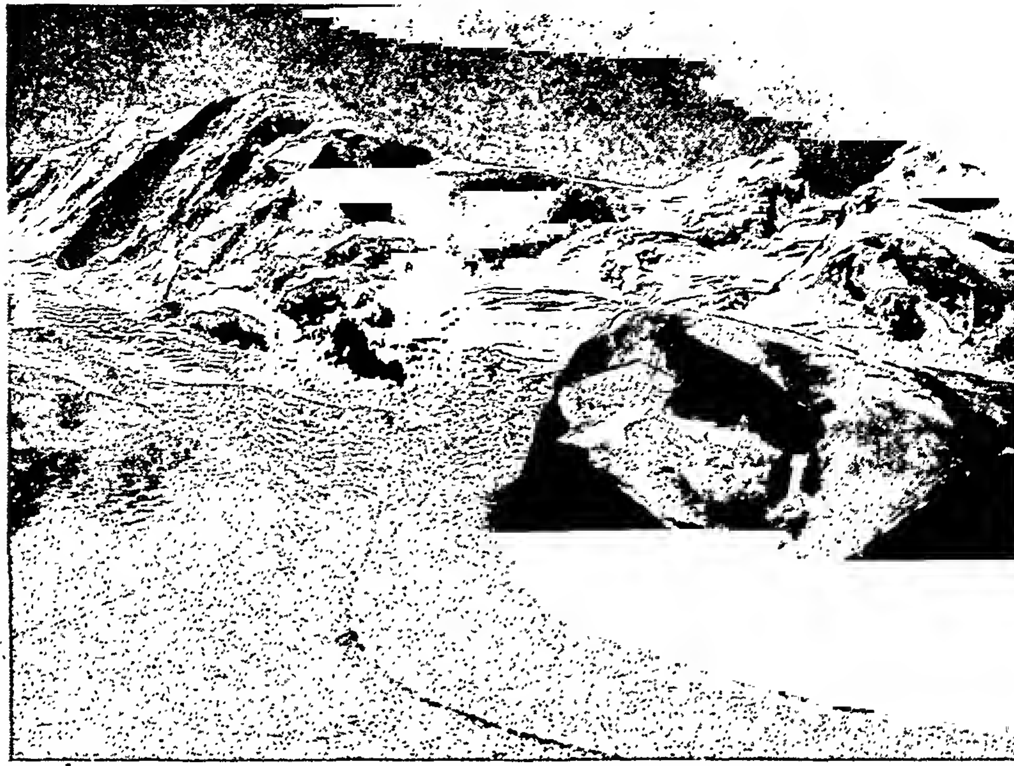


Fig. 16. The Gorner glacier above Zermatt in Switzerland. The mountain on the left is Tyskamus and the two on right are Castor and Pollux. Like the Mer de Glace, the Gorner is 9¼ miles long. These two are the longest glaciers in the main chain of the Alps.

360 ft. a year. But the rate of movement of the Mer de Glace in the French Alps is from 20 to 27 in. a day at the centre, and from 13 to 19½ in. at the sides.

THE HUGE SWISS GLACIERS

There are some 470 large glaciers in Switzerland, the longest being the Grosser Aletsch in the Bernese Oberland (Fig. 15), which is 16 miles in length and 1,968 yards in breadth at its widest part; the Unteraar Glacier and the Gorner (Fig. 16), both 10 miles in length; and the Viescher, 9¼ miles in length. The Aar Glacier requires about 133 years to descend the full ten miles of its length. The movement of the glaciers in the Polar regions is generally more rapid than those of the Alps. The Garwood Glacier at Spitzbergen moves 800 ft. a month, and the Karajak Glacier (Drygalski) 1,500 ft. a month. Jacobshavn Glacier, on the west coast of Greenland, moves from 50 to 75 ft. a day; and Upernivik Glacier 99 ft. a day in summer.

The greatest glaciers in the world are found in the Polar regions, and beside them the Alpine glaciers fade into insignificance. Over $\frac{5}{7}$ of the whole area of Greenland, about 700,000 sq. miles, is buried beneath an enormous mass of ice. From it great glaciers, from 2,000 to 3,000 ft. thick and over 50 miles in width, creep down the valleys to the sea. Here they terminate in vertical faces from 100 to 1,000 ft. in height, from which they break off to form icebergs. On the west of Greenland, at a distance of 130 miles from the coast, there is a solid wall of ice 6,000 ft. in height. Measurements

Fig. 17. The course of a glacier, showing how it forms icebergs on reaching the sea.

show that over the centre of Greenland the ice cap is nearly 9,000 ft. thick. North-east Land, Spitzbergen, a broad plateau with an area of 6,200 sq. miles, is covered by an ice sheet 3,000 ft. thick, which is slowly moving to the east, and discharges into the sea as a huge wall of ice, unbroken for a distance of 150 miles. Water from the melting glaciers drains off in rivers some of which are 30 miles in width. Among the more notable glaciers of the Arctic is the Great Dove Glacier, 60 miles in width, in Franz Josef Land.

Although ice is plastic, it is not able to withstand tensional stresses, and will break if stretched. In flowing through a winding valley there are naturally many such stresses that the ice is unable to withstand, and it fractures. These cracks, which are known as crevasses, generally lie across the direction of flow. Subsequent movements increase their size, so that one commencing as a mere crack in which it is difficult to insert the blade of a knife may become a gaping chasm, 1,000 ft. in depth. Often these crevasses are covered with snow and so remain hidden. Numerous lives have been lost when mountaineers, failing to detect a crevasse beneath have fallen into it.

Sometimes the bodies of these unfortunate people have been preserved in the ice and have re-appeared at lower levels after an interval of several years. One well-known case was that of Henry Arkwright who in 1866, when climbing Mont Blanc, was carried away by an avalanche. Thirty-one years later his body was disclosed at the foot of the glacier, having descended over 9,000 ft. in the ice in the intervening period. During the following month many of Arkwright's belongings were also recovered from the glacier including his gloves, tied together with a piece of bootlace that his sister remembered handing to him before he commenced his fatal journey. His handkerchief and shirt were also recovered, and despite the fact that it had been encased in the ice for thirty-one years the studs remained in the button holes. His pencil case opened as smoothly as on the day he was lost.

Fig. 18. A dark millstone—grit rock lying on the white limestone at Clapham, Yorkshire. This rock was carried here by a glacier many hundreds of thousands of years ago.

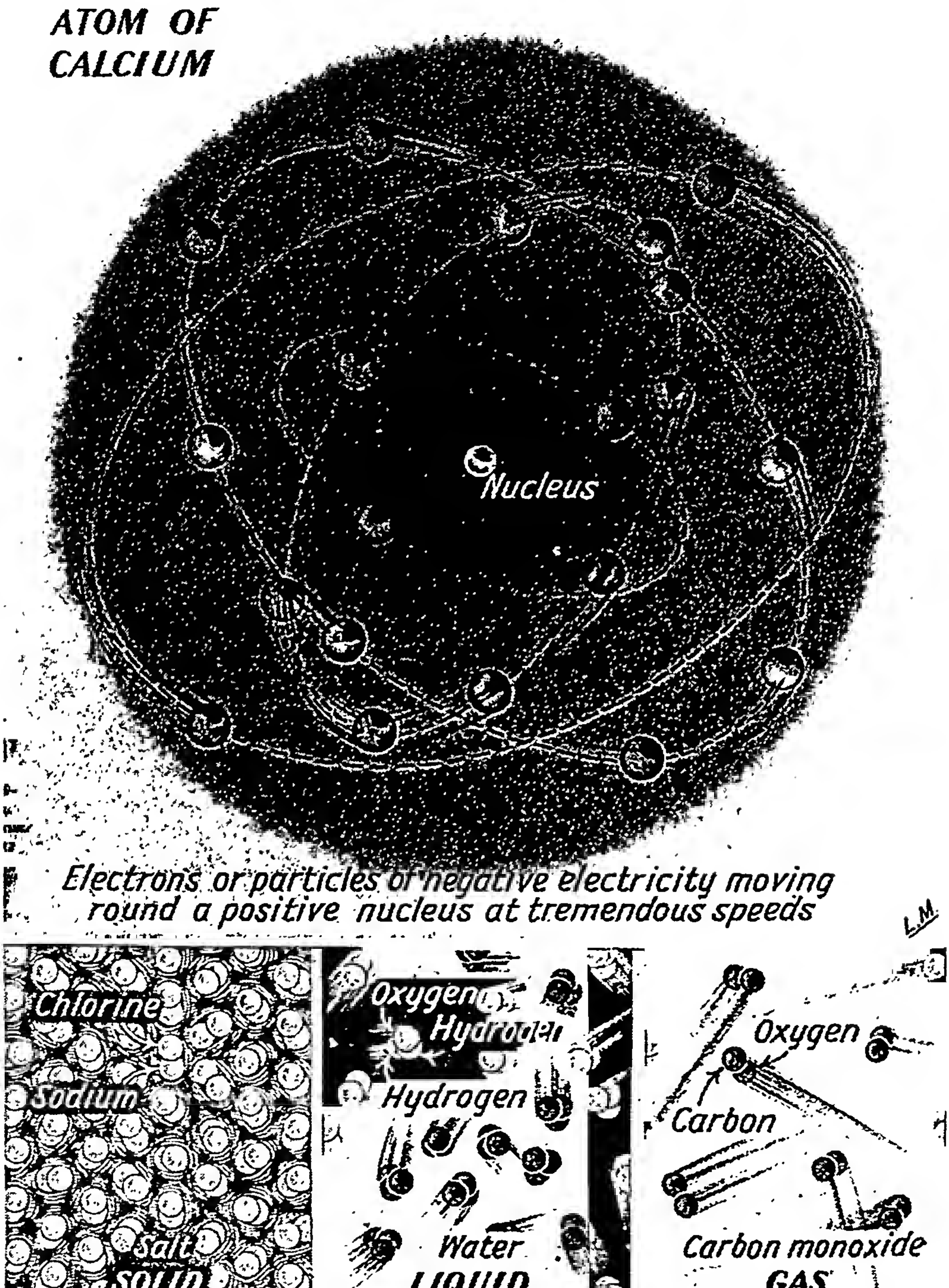
Glaciers carry a considerable amount of material along with them, and when this material is carried on the surface it is known as a moraine (Figs. 15 and 17). Much of the material comes from the sides of the valley, some being detached by the grinding action of the glacier itself

and some falling on to the glacier from the sides above by the action of frost and rain. When two glaciers meet and joint together the right lateral moraine of one and the left lateral moraine of the other, unite and form a central, or medial, moraine (Fig. 17). By the number of these central moraines on a glacier one can tell how many tributary glaciers have contributed to the main mass. The materials are ultimately deposited at the termination of the glacier, where they form a terminal moraine.

Fig. 19. Scratches on mica-schist rocks near Roy Bridge, Inverness-shire, made by the passage of a glacier in prehistoric times.

At Clapham in Yorkshire there are to be seen large dark rocks of millstone grit standing on the white limestone (Fig. 18). At Cloughmore, Rostrevor, Co. Down, blocks of granite rest on a bed of slate. In many other places, too, may be seen large and small rocks lying on strata of an entirely different formation. The presence of these "erratic blocks", as they are called, is evidence of glacier action in bygone times. They have been carried—often great distances from their parent formation—by a glacier which, when it has melted, has left the erratics stranded in strange surroundings. In many places in this country we can see where prehistoric glaciers have been at work. Especially is this so in Scotland, in the Lake District and in North Wales, where rocks bear great cuts and scratches showing that a glacier has passed over them (Fig. 19). From the appearance of the scratches we can even determine the direction in which the glacier was moving.

Glaciers play an important part in the work of denudation, grinding away the land and scouring out valleys. We can always tell that a glacier has been at work, for this is evidenced by the fact that glacier-worn valleys are U-shaped, whereas V-shaped valleys owe their origin to the action of rivers. The whole process of glacier formation and action is seen in Fig. 17.



Imaginative pictures of the atom and the molecule. An atom consists of one or more negative electrons revolving round a positive nucleus. The whole atom is normally neutral because the charge in the nucleus balances those in the electrons. A molecule consists of two or more different atoms. The lower pictures show the molecules of a solid, a liquid and a gas.

SECTION III

THE CONSTITUTION OF MATTER

CHAPTER 11—THE IMPORTANCE OF THE ATOM

BEFORE we can consider the mysteries and marvels of Sound, Heat, and Light—to be dealt with in later sections—it will be well for us to learn something about the constitution and the properties of matter, so that we shall be better able to understand the nature of the phenomena we are to describe.

Contrary to some people's ideas, matter is not always a hard substance. Although many would hesitate to describe air or gas as matter, yet the stuff of which water, for example, consists, is still matter whether it exists as ice, as water, or as the constituent gases oxygen and hydrogen. Thus, it must be understood before we go further, that matter may exist in solid, liquid, or gaseous forms.

John Stuart Mill, the philosopher, defined matter as a "permanent possibility of sensation," but this is too indefinite for the scientist. Probably a more satisfactory definition is: matter is that which occupies space, has weight, and has the property of being extended.

Matter may be studied from three aspects. The mathematician may investigate the behaviour of matter under the action of various forces; the physicist may endeavour to discover its properties; and the chemist may investigate the results of combining some of its varying forms.

The constitution of matter has engaged the attention of thinkers and scientists at least from the time of the Greeks. They appear to have been the first to speculate on the theoretical aspect of the practical application of the various properties of matter, although some of these applications dated even from prehistoric times. Thales of Miletus (640–546 B.C.), chief of the Seven Sages and Founder of the Greek School of Astronomy, attempted to solve the problem of the substance of which the world is composed. He came to the conclusion that all things are composed of water in various states of condensation or rarefaction.

EARLIEST ATOMIC THEORY

Democritus, who was born about 460 B.C. and became one of the greatest of the Greek philosophers, held the opinion—most remarkable in the light of recent investigations and present day theories—that matter is composed of atoms that are always in motion. "According to convention", he wrote, "there is a sweet and a bitter; a hot and a cold; and according to convention there is colour. In truth there are atoms and a void". He held that all atoms are alike of the same substance, although of various sizes and shapes; that they form different kinds of matter by their difference in size and by their different arrangements and positions. In this, Democritus anticipated the modern atomic theory in a surprising way.

On the other hand, other Greek philosophers thought matter could be classified as four elements—earth, water, air, and fire. Aristotle, for example, pointed out that when green wood is burned, there resulted the constituent four elements: *fire; air*, or smoke; *water* that oozes from the wood; and ash of an *earthy* nature. These early Greek

ideas were the basic principles of physics for centuries and were only slightly modified by the work of the great Arab scientists and the alchemists.

The alchemists, the forerunners of the modern chemists, undertook in the Middle Ages the quest for the "philosopher's stone". They were convinced that its discovery would enable them to convert the baser metals into gold and silver. They believed that metal made to *look* like gold actually was transformed into gold. In other words, in their view, the actual composition of a metal was relatively unimportant as compared with the colour of the metal.

FROM ALCHEMY TO CHEMISTRY

Avicenna (980–1037), the great Arab scholar, was the first to maintain that colour had little relation to the difference between metals. He held that the transmutation of a base metal to gold involved more than a mere change of colour. Despite his theories the endeavours to find the "philosophers' stone" continued and little was done to discover the fundamental nature of matter or to revise the earliest ideas about it. How seriously the alchemists were taken may be judged from a law of Henry IV, enacting heavy penalties on those who multiplied gold or silver!

Such ideas as these persisted until the 17th century when Robert Boyle (1627–91) taught that material substances must be classified very differently. The ancient idea of the Greeks, that burning always resolves a substance into its constituent elements, was shown to be erroneous, Boyle demonstrating that sometimes a complicated substance instead of an elementary substance still remains after the application of heat. He held that some substances remain unchanged despite the application of heat.

From this time dates the important distinction that matter consists either of simple substances called elements, or compounds of these elements.

An element is a substance composed entirely of atoms that have identical properties. To distinguish between elements and compounds required many years of research, largely contributed to by a Manchester schoolmaster John Dalton (1766–1844), the real originator of modern atomic theory.

Compounds consist of two or more elements in combination—water, for instance, is a compound of the two elements hydrogen and oxygen. The smallest particle of a compound is the *molecule*, and this varies in size according to its composition. Although an ordinary microscope will show a mass so minute that it covers an area of only a millionth part of a square inch, the most powerful microscope in the world cannot make visible the largest molecule. If we were able to measure a molecule of water we should find it to be about $\frac{1}{50,000,000}$ centimetre in diameter. We can get some idea of what this means by supposing that a drop of water could be magnified to the size of the Earth—about 8,000 miles in diameter. The molecules of which it is composed then would be about the size of golf balls (Fig. 1).

MOLECULES AND ATOMS

Although the distances that separate the particles in any matter are inconceivably minute by our standards of measurement, these molecules are in constant motion, moving about with enormous velocities. The direction of their movement is altered thousands of millions of times a second, through collisions with other molecules.

Molecules themselves are made up of even smaller particles of matter, called *atoms*. Every molecule consists of a combination of two or more different atoms. Dalton showed that when atoms combine to form any compound they

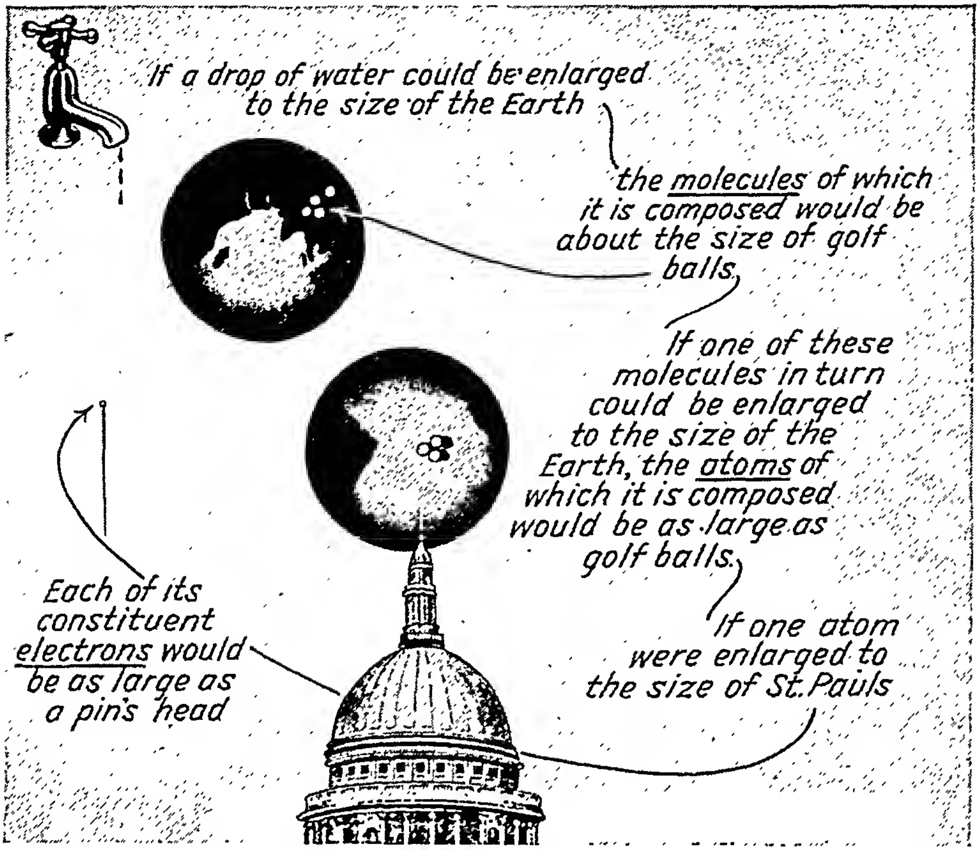


Fig. 1. Relative sizes of molecules, atoms and electrons. This figure shows how impossible it is that we should ever see one of these even through a super microscope.

always do so in definite proportions by weight and so form the characteristic of the compound. If two or more elements combine to form more than one compound they combine in simple multiples of these definite weights. It is important to get clear the fact that a molecule is a compound whereas an atom is an element.

If we are unable to see a molecule with our most powerful microscope, it is obvious that we cannot see an atom, for this is infinitely smaller. So far as comparative size is concerned, an atom may be said to stand in the same relationship to the molecule as the molecule does to the Earth. That is to say, could we magnify a molecule to the size of the Earth, the atoms in it would be about the size of golf balls (Fig. 1). That great physicist Lord Kelvin gave a striking illustration of the size of the atom. He pointed out that the microscope is able to show certain *infusoria* so minute that an individual specimen can lie between two divisions of $\frac{1}{25,000}$ in. This minute measurement must be considered to be relatively enormous when compared with an atom, for it would lie between two of $\frac{1}{700,000,000}$ in. (one seven hundred millionth of an inch)! Even had we the means to magnify an atom, it would be invisible for it could not be made to reflect a ray of light. The reason for this is that it is much smaller even than a light-wave.

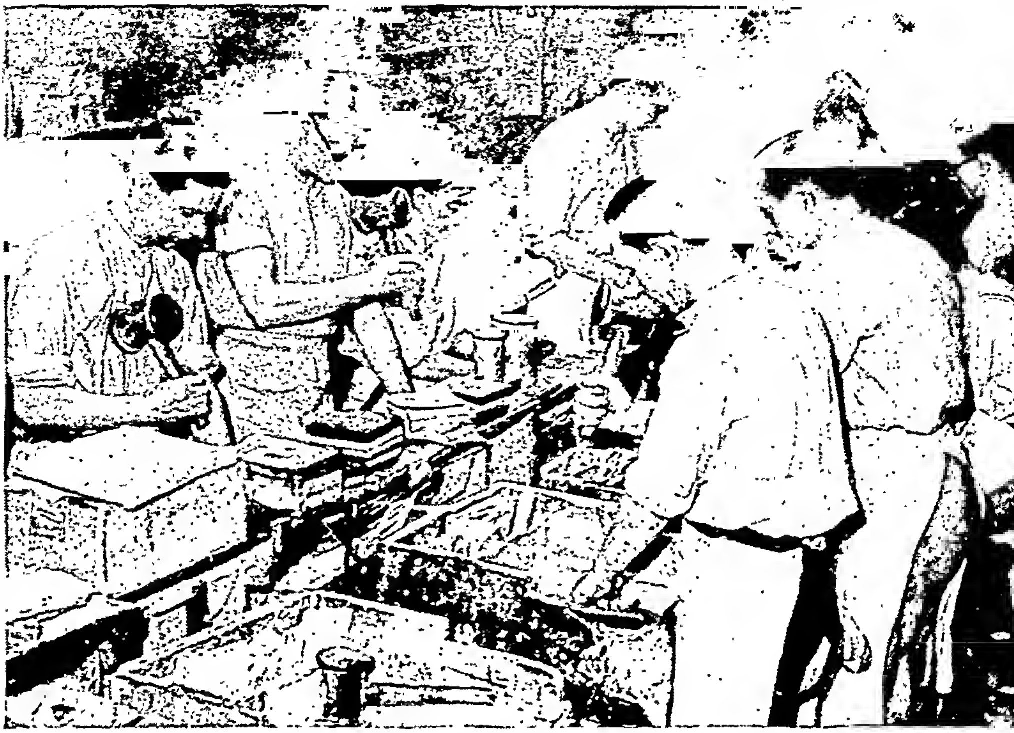


Fig. 2. Gold-Beaters at work. Gold can be beaten into an astonishingly thin sheet. A pile of a thousand such sheets would be about as thick as a sheet of paper.

We cannot obtain an atom by the division of a particle of matter, though in the workshop we can divide matter to very fine limits, as, for example, in gold leaf. In preparing this (Fig. 2), the beater takes a piece of gold one inch square and $\frac{1}{1,000}$ in. thick, and places it between the leaves of a "cutch" consisting of 200 sheets of fine vellum. These are then beaten for thirty minutes with a 20-lb. hammer until the gold covers the same area as the sheet of vellum, which is about 4 in. square. The sheet of gold is then divided into four equal parts, and the beating repeated, but for two hours. The vellum is replaced by a "shoder", consisting of 800 coarse strong skins, $4\frac{1}{2}$ in. square. The leaves of gold spread to the edges of the skins and are once again quartered, and placed between the skins of a "mould" composed of 1,000 very thin sheets of "gold-beater's skin". This is an exceedingly thin and tough membrane from the intestine of the ox, a thousand of which measure less than 1 in. in thickness. The gold leaves are beaten for five hours with an 8-lb. hammer, until finally by this great feat of craftsmanship a gold leaf $\frac{1}{250,000}$ in. thick is obtained. A pile of about 1,000 of such leaves would approximately equal the thickness of this page.

FINENESS OF GOLD WIRE

Even this almost incredible fineness is surpassed by fine-drawn gold wire, 3,530 yards of which can be drawn from a single grain of gold, forming a wire with a fineness of $\frac{1}{5,000,000}$ in.

If the finest possible particle were cut from one of these sheets of gold leaf or from the end of this incredibly fine wire, we should not even then have obtained an atom of gold!

The number of atoms in each molecule

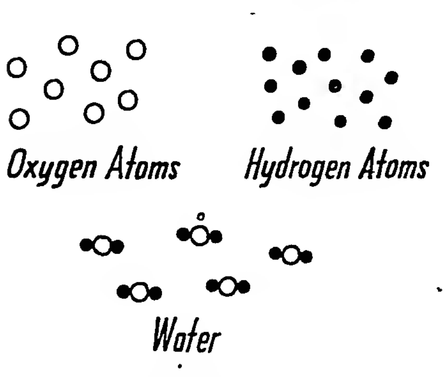


Fig. 3. Two hydrogen atoms and one oxygen atom combine to form a molecule of water.

of a compound determines what that compound is, and for each compound a definite molecular structure has been worked out. For instance, two atoms of hydrogen and one atom of oxygen form a molecule of water (Fig. 3). On the other hand, should there be two atoms of hydrogen and two atoms of oxygen, the resulting compound will not be water, but hydrogen peroxide. Similarly, one atom of sodium and one atom of chlorine form a molecule of common salt (sodium chloride). Two atoms of oxygen and one atom of carbon make carbon dioxide (A, Fig. 4), whilst one atom of oxygen and one atom of carbon make the deadly gas, carbon monoxide (B, Fig. 4), and so on through the whole catalogue of substances.

Working downwards from the molecule to the atom we find that there is a rather important distinction to mention between molecules and atoms. A molecule is the smallest part of a substance that can retain the characteristic properties of that substance, whilst an atom is a particle that has entirely new properties.

Dalton determined twenty separate elements and to this number subsequent research added 72, making, in all, 92 elements. These elements, either combined with other substances or, more rarely, uncombined, form all matter. Of them everything in the world—the whole world itself—is composed. These 92 elements may be briefly defined as those substances that it has so far proved impossible to break down into other substances with different properties. Gold contains only one kind of matter and is therefore an element. Silver is another element. Even a microscopic speck of silver consists of an assemblage of silver atoms, each of which is about $\frac{1}{100,000,000}$ in. in diameter.

Many substances at one time thought to be elements have since been shown to be compounds. Quite possibly some others of the substances still classed as elements will yet prove to be compounds.

The elements themselves exist as solids, such as gold and silver; gases, such as oxygen and hydrogen; or a liquid, such as mercury.

We have here assumed that only 92 elements are known, but it was announced in June, 1934, that an Italian physicist had discovered "Element 93". It was said to have been evolved from the element uranium. Four years later (August, 1938), Prof. Perrin of the French Academy of Science announced that "Element 93" had been isolated in

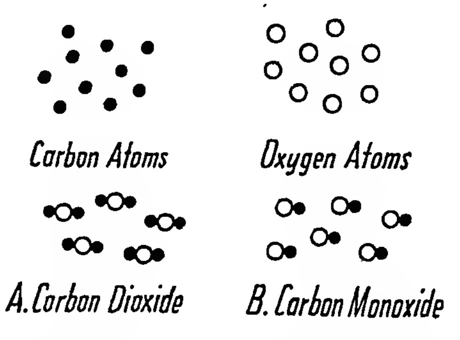


Fig. 4. (A) Two oxygen and one carbon atom combine to form carbon dioxide. (B) One oxygen and one carbon atom combine to form the deadly gas carbon monoxide.

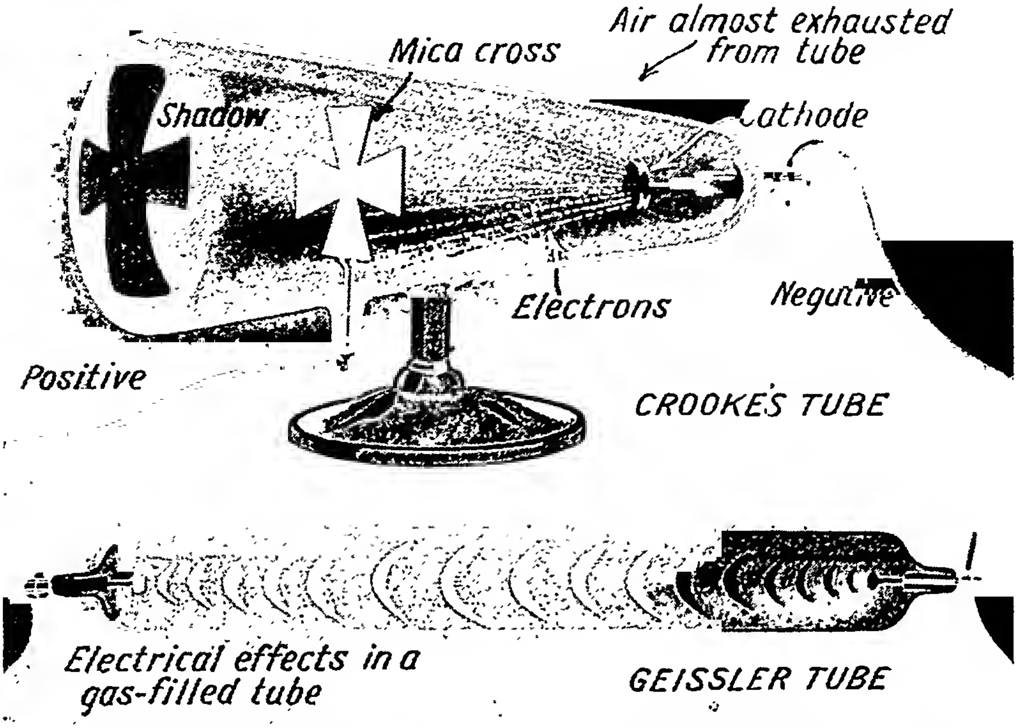


Fig. 5. Sir William Crookes discovered that when an electric current was passed through a tube almost empty of air, the tube became filled with phosphorescent emanations. These cathode rays resemble light in that an opaque object (Maltese cross in diagram) introduced in their path causes a shadow. Unlike light rays, cathode rays are sensitive to a magnet.

France and that its discoverers had called it "Transuranien". Discovered in pitch blende, it is radio-active, like radium, and uranium (Element 92).

BEYOND THE ATOM

So far, then, we have travelled from a drop to a molecule, and from a molecule to an atom. We have seen that an atom of silver is the smallest particle that might be obtained as silver. Now, is the atom the end? Can we not go a step further in our investigations? Modern research shows us that though we have not the means to do it and can only go part of the way to this end, if we could break up a silver atom we should find that the resultant particles are not silver particles at all, but consist of something else.

Take for example the case of water, the solid form of which is ice. We know that the melting of ice releases the molecules of which it is formed, so that the solid changes to liquid; that heating the liquid enables the molecules to move independently so that the liquid changes to steam; and that the steam enables the molecules to break up into their constituent atoms of oxygen and hydrogen. Beyond this our laboratories cannot go, but we believe that in the great laboratory of the Sun a further heating can break up even atoms. The process begins at the Sun's surface and it is very probable that, with the enormous pressures and temperatures of the Sun's interior, atoms are broken up and the fragments packed so densely together that a thimbleful would weigh as much as 1 lb., or even more.

This belief is comparatively new, for until the close of the 19th century it was thought that the atom was the ultimate

particle of matter and was indivisible—indeed, its name actually comes from the Greek word *atomos* meaning "not divisible". Atoms were thought to be minute solid bodies of different sizes and shapes, rather like microscopic grains of sand. Clerk Maxwell (1831-79) thought that these grains were "the foundation stones of the material universe that have existed since the Creation, unbroken and unworn".

It was the experiments of Sir William Crookes (1832-1919), who passed electric currents through vacuum tubes, and the discovery of Rontgen rays (or X-rays as they are more commonly called) that provided the first steps towards a revolution in scientific thought. This completely changed the accepted theories of the constitution of matter. Sir William showed that when an electric current was passed through a glass tube almost exhausted of air, a stream of particles passed from the plate or electrode at one end of the tube to the electrode at the other end (Fig. 5). Sir Joseph Thomson, showed (in 1897) that this stream consisted largely of negatively-charged particles that had less than one-thousandth of the mass of the hydrogen atom, the lightest element and that which it had been suggested constituted the fundamental substance of all matter. It thus became evident that the atom of hydrogen could no longer be regarded as the smallest particle, for these electrified particles were demonstrably more minute.

WHAT ELECTRONS ARE

Mathematicians proceeded to determine the precise nature of these small particles, which were named electrons. It was already known that when a body carries an electrical charge it behaves as though it has a greater mass than it has when not charged. The mystery to be solved was how much of the mass of an electron was due to its electric charge. The amazing result of this investigation was the announcement that the whole of the mass of the electron was due to the electric charge—in other words, the electron was no further subdivision of an atom of matter but was in effect an electric charge itself. Thus it was that the great revolution in our conception of matter was brought about. By it a universe of matter gave place to a universe of electrical charges!

It was further determined that these electrons consist of particles of negative electricity. As atoms are not electrified in their normal states, it became obvious that they must also carry a charge of positive electricity that counterbalances the negative charge. Gradually the physicists built up an idea of how these charges were arranged in an atom. They ultimately came to the conclusion that the electrons, or negative charges, revolve around a very small nucleus, where all the positive electricity is concentrated (Fig. 6). This central nucleus, called the proton, bears the same relation to the whole atom as the Sun bears to the solar system.

Electrons revolve around their nucleus in a somewhat similar way to that in which the Earth revolves around the Sun. Their velocity is terrific—20,000 miles a second or more. Indeed, the

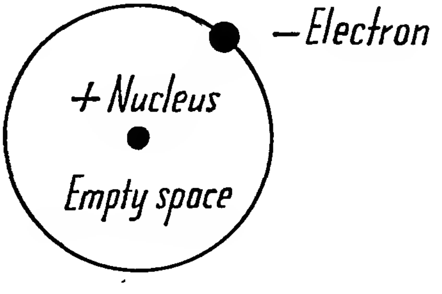


Fig. 6. How the electron revolves round the positive nucleus in the atom of hydrogen.

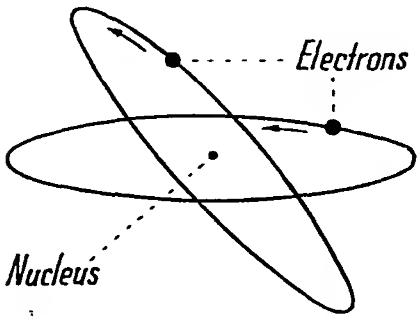


Fig. 7. Disposition of electrons in an atom of helium—one of the simplest atoms.

speed of revolution is so fast—or, to express it another way, the atomic year is so short—that over a billion atomic years may pass at the snap of a finger! If there could be any ultra-microscopic "people" living on these planet-like electrons they would have a time-scale totally different from ours. As time is only relative, however, there is nothing impossible about this. Atomic people could live their lives, nations could rise and fall, and the tiny atomic world grow cold in the tick of a terrestrial clock!

The number of electrons in an atom, and the method of their arrangement in relation to the central nucleus, determine its properties. The simplest atom is the hydrogen atom. It consists of a central positive charge with one electron revolving around it—rather like the Earth and the Moon, we might suppose (Fig. 6). The next simplest atom is that of helium, in which are two electrons revolving around the central nucleus (Fig. 7). It is a well-balanced self-satisfied system and consequently does not mingle with other atomic systems. Other atoms have a greater number of electrons. Sodium, for instance, has eleven and calcium twenty electrons (Fig. 8), revolving in three and four orbits respectively.

Some atoms are of a highly complex structure, as for instance an atom of radium. This is a very heavy atom with a nucleus so complicated as to be unstable. This results in a state of disintegration that cannot be stopped no matter what is done to this end. Consequently, radium gives out certain emanations. These are of three kinds, known as the *alpha*, *beta*, and *gamma* rays, and they consist of a constant stream of particles made up of protons and/or electrons. The particles of the *alpha* rays consist of four protons and two electrons, a combination that is

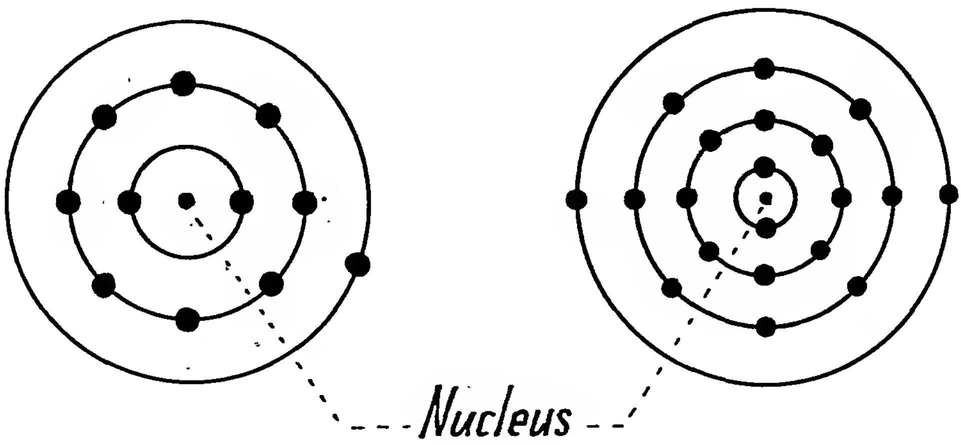


Fig. 8. On the left is an atom of Sodium, on the right an atom of calcium.

of the same constitution as the nucleus of an atom of helium. The *beta* rays consist of particles composed entirely of electrons. The *gamma* rays are not particles but a form of very short rays of the same kind as X-rays. Why the atoms of radium should disintegrate in this way is at present a mystery of science, but the emanations are used in medical work as they have been found to have a beneficial effect in certain diseases, notably cancer.

DIAMETER OF AN ELECTRON

To measure the diameter of an electron mechanically is quite impossible, but it has been calculated that it must be approximately $\frac{1}{100,000}$ the diameter of an atom. Thus, could we magnify an atom to the diameter of 100 ft., each electron would be about $\frac{1}{100}$ in. in diameter. If a bubble of hydrogen gas the size of this letter o were enlarged so that it was the size of the Earth, each atom—of which there would be billions—would be as large as an orange. If one of these atoms was enlarged to the size of St. Paul's Cathedral each electron in it would be the size of a pin head (Fig. 1). The nucleus would be about as large as this full stop . This central nucleus would be very heavy in comparison with the planetary electrons.

No doubt when reading the chapter on astronomy we considered the solar system a marvellous arrangement, but how much more marvellous are these atomic solar systems in their minuteness. Here electrons move around a central nucleus at speeds of 20,000 miles a second or more, in orbits that may measure no more than the infinitesimal size of one thousand-millionth of an inch in diameter!

There is a remarkable similarity between the constitution of atoms and that of the universe. The physicists tell us that if we could magnify a helium atom so that it became the same size as the solar system in which its positive nucleus would correspond to the Sun, its two negative electrons would closely resemble Uranus and Neptune as regards comparative size, distance from the centre, and period of revolutions.

From these illustrations it is clear that an atom is largely composed of empty space. It has been said that if all the electrons in a human body were to coalesce so that they formed a solid central mass, the whole would form a speck no large than this full stop .

Fournier d'Albe believed that each tiny electron may have a constitution resembling that of the Earth in every particular—that each may be a veritable microcosm, a world on which life may flourish not very different from life on the Earth! D. I. Mendeléeff (1834–1907) the great Russian chemist, suggested that the whole of the visible stellar universe, with its millions of suns in constant motion, is merely a large-scale model of the atomic universe. Similarly, Anatole France has suggested that our universe may be only an atom in some larger system, and whimsically remarks that he could find no reason to deny that our universe might be merely an atom in the leg of some "super dog" barking in a "super world", itself only a unit in some still greater system, and so on *ad infinitum!* Ludicrous though this flight of fancy seems, it gives food for thought on one of the greatest and most fascinating mysteries of science.

MYSTERY OF MAGNETISM

As we know, in magnetism "like repels like". This is clearly shown if a bar magnet is allowed to hang freely by a cord, and the north pole of a second magnet is brought near the north pole of the hanging magnet. There is then a marked repulsion (Fig. 9). On the other hand, that "unlikes attract" may

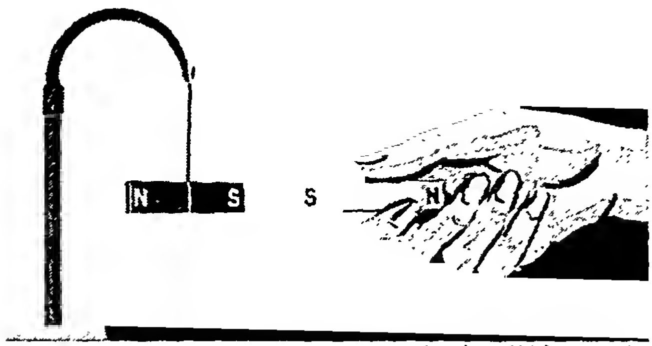


Fig. 9. Demonstrating the magnetic principle that "like repels like". There is no attraction between the two South Poles.

millionth of a second. Then the electron is caught and attached to an atom and its career ends. But only for the fraction of an instant, for barely has the atom taken in the new electron than ether waves again disintegrate the atom, and with a great explosion the tireless electron starts off on its impetuous career again.

be demonstrated by bringing the south pole of the second magnet near the north pole of the hanging magnet (Fig. 10). A similar principle obtains in the case of electrons, for being negative charges of electricity, they repel each other.

As we have seen, the negative charge of an atom equals the positive charge, so that regarded as a whole such an atom has no charge at all, on balance. Should an atom pick up some electrons it becomes negatively-charged. On the other hand, should it lose some of its electrons it becomes positively-charged, for then it has more positive than negative electrons. Such a process is called ionisation, the charged atoms being known as *ions*. It is believed that the attraction of oppositely charged atoms for each other is the basis of the structure of matter.

Amazing changes take place through ionisation in the stars, where temperatures and pressures beyond our powers of conception strip the electrons from the atoms. The inside of a star must be the scene of ceaseless struggle between atoms, electrons, and ether waves. The disintegrated atoms move at enormous velocities of over fifty miles a second, with their electrons torn from them. They experience a thousand near-collisions in the ten-thousand

In an atom the electrons are held comparatively loosely and so are affected by ordinary chemical reactions. There is a general tendency in the atoms of metallic elements to lose electrons, but on the other hand the atoms of non-metals have a tendency to acquire additional electrons. Thus, when sodium combines with chlorine to form sodium chloride, an electron has been lost by each atom of sodium and acquired by each chloride atom. As each sodium atom was originally electrically neutral, and as each has now lost a negative charge, it becomes converted into a sodium ion with an extra positive charge. Similarly, each chlorine atom becomes a chlorine ion with an extra negative charge of electricity.

ENERGY STORED IN AN ATOM

Because of the enormous speeds with which the planetary electrons move around the central nucleus, an atom stores up an immense amount of energy. An ounce of radium would give out sufficient heat in an hour to raise one and a half ounces of water to boiling point. The discovery of this state of affairs gave rise to the idea that if only the atom could be "split" this enormous energy would become available. It has been stated that if the atoms of one gram of hydrogen could be exploded simul-

taneously, sufficient energy would be produced to lift 1,00,000 tons to over 300 ft. According to Dr. Brasch, a German physicist, if a ton of coal could be treated atomically, sufficient heat would be generated to melt all the ice in the North Polar Cap! In 1932, Drs. J. D. S. Cockroft, and E. T. S. Walton of Cambridge succeeded in "splitting the atom", using a high-tension current of 120,000–600,000 volts. Later in the same year Brasch and Lange in Berlin, using a cathode tube and 2,400,000 volts, announced that they had disintegrated the atoms of six different elements. In neither of these experiments was there any sudden access of energy, however, and in 1933 Lord Rutherford characterised as "moonshine" the claims of those who expected that the splitting of the atom would release any mighty store of energy.

Could we annihilate matter, we should theoretically, obtain an intense source of energy. Similarly, by causing an electron and a proton to coalesce, an inconceivable amount of energy would be released. We do not know how to do this, nor how we could harness the resulting energy if it could be done. It seems likely, however, that this process is occurring in the Sun and in the stars, which, as we have already seen, radiate enormous energy. Here, perhaps, matter is being annihilated, but such is the vastness of their masses that the constant drain on their resources has little effect. The Sun, for example, is parting with 360,000,000,000 tons of matter every day but there remains sufficient matter to last for 15,000,000,000,000 years!

What really happens when the atom is "split" is that as the 92 elements are all made up of fundamental electrons and protons, we simply convert one element into another when we manage to alter the composition of the nucleus. An additional particle is introduced, or the nucleus is caused to expel a particle. In 1919 Rutherford and Chadwick transmuted a number of the lighter elements. Since that time great advances have been made and to-day splitting the once indivisible atom has become the ordinary occupation of the physicist. An atom that for the last thousand million years has existed as silicon may to-morrow find itself transmuted into an atom of phosphorus! This splitting of the atom must not be confused with the tracking down of a molecule. In the latter case two or more substances are obtained, in the former one element is changed into another.

CHANGING ATOMIC STRUCTURE

If one proton and one electron could be removed from each of the atoms of 1 lb. of mercury we should have instead 1 lb. of gold and the dream of the ancient alchemists would be realised. To-day, the alchemist's successor is not so much concerned with the transmutation of lead into gold, as with the benefitting of humanity as a result of his researches. To this end, a 50-ton

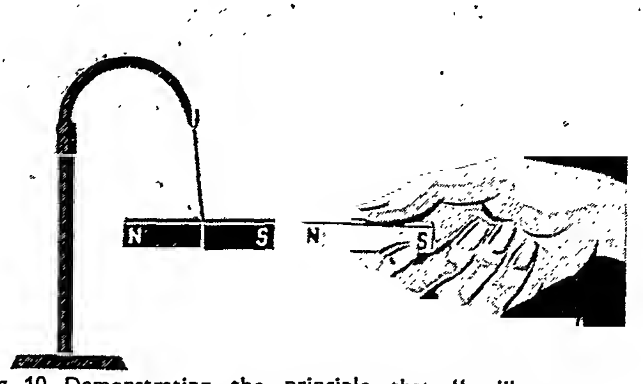


Fig. 10. Demonstrating the principle that "unlikes attract unlikes". Fixed North has pulled free South towards it.

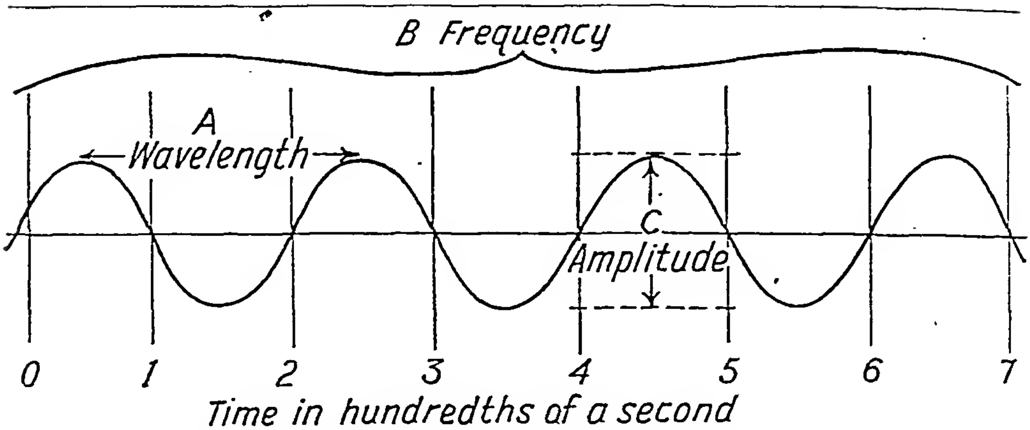


Fig. 11. The three principal characteristics of waves: frequency, amplitude and wave-length.

machine, called the Cyclotron, was installed in the year 1939 at Liverpool University for converting certain substances into radio-active substances by altering their atomic structure. These substances will enable extended treatment to be given for cancer and other ailments at less cost than is required for radium treatment, and in a simpler and much more convenient manner.

WAVES AND WAVE-MOTIONS

Waves and wave-motions are directly concerned in the phenomena of Sound, Heat, and Light, and the study of waves is a natural preliminary to the understanding of those subjects. Sound, for instance, is a form of energy, and energy is transferred from one place to another by one of two methods. Firstly, there is the transfer by actual motion of a substance containing energy—such as coal, gas, or steam. Secondly, there is the transfer of energy by wave-motion, and in this form—as in Sound, Heat, and Light—the transfer is accomplished without the movement of any material from one place to the other. In these cases of wave-motion takes place in some medium—for instance the air for Sound, or the ether for Heat and Light. This ether is the same medium we read about in connection with radio waves, which are closely allied to light-waves, as we shall see when we come to consider them in a later section of this book.

As an example of the two different methods of transferring energy—that is, actual motion and wave-motion—we can instance the moving of a piece of wood that floats in a pond. The first method may be demonstrated by actually hitting the floating wood with a stone. The second method is illustrated by dropping a stone in the water near the edge of the pond, so causing waves to spread over the surface of the pond until they reach the wood and move it up and down. In this latter case it is important to realise that the water itself does not move, but a wave of energy spreads over its surface so causing the wood to move.

Waves may be surface waves, as on the pond when the stone was dropped into the water; or they may be waves passing through a solid, a liquid, or a gas. Surface waves are due to the water being heaped up, as by the dropping of the stone; or by wind blowing on a sheet of water and causing depressions in it. The water tries to restore the normal level of its surface, and runs down the inclines caused by the depressions. Momentum carries it below the former surface level, so forming a "trough" and setting up a motion that is passed on to neighbouring particles. The motion

spreads as a wave over the entire surface.

The other kind of waves start from some vibration and travel in straight lines. They form a constantly expanding succession of spheres, as it were, the centre of which is the point from which the vibrations originate.

HOW WAVES VIBRATE

Wave-motion may take place in more than one direction. In the case of light, for instance, the vibrations are at right angles to the direction in which the disturbance moves. Such vibrations are said to be *transversal.* In the case of sound, the waves move in the same direction as the direction of travel and are said to be *longitudinal.* That is to say, the oscillations of the particles are in the direction of the propagation of the wave and not at right angles, as in the case of light.

Any wave moving through a medium —whether it be gas, liquid, or solid— has three principal characteristics. The *wave-length* is the distance from one part of the wave to another similar part (A, Fig. 11). The *period* or *frequency* is the time taken by any particle of the medium to describe a complete vibration (B, Fig. 11). Finally, the *amplitude* is the amount of motion (C, Fig. 11). In ocean waves this corresponds to the height of the crest or depth of the trough measured from the level of the undisturbed sea.

These three characteristics may be illustrated with a length of rope fastened at one end to a fixed support. If the other end of the rope is given a rapid up-and-down movement, a series of displacement waves is caused to travel along the rope (Fig. 12). Any part, such as A-B, is a replica of another part, such as B-C, or C-D. Each part forms one wave with a definite wave-length as A-B. This is better illustrated in Fig. 13, where a thread is attached to the hammer of an electric bell mechanism, the motion of which causes regular periodic waves of constant amplitude to occur in the thread.

Wave-length, which is usually denoted by the Greek letter *lambda* (λ) is the distance from the crest of one wave to the crest of the next, or from one trough to the trough of the next (Fig. 12). The term wave-length is also used to designate the distance the wave travels in the time taken for one complete vibration of one of the particles of the the medium (which, as we have said, is the *frequency*).

The extent of the greatest displace-

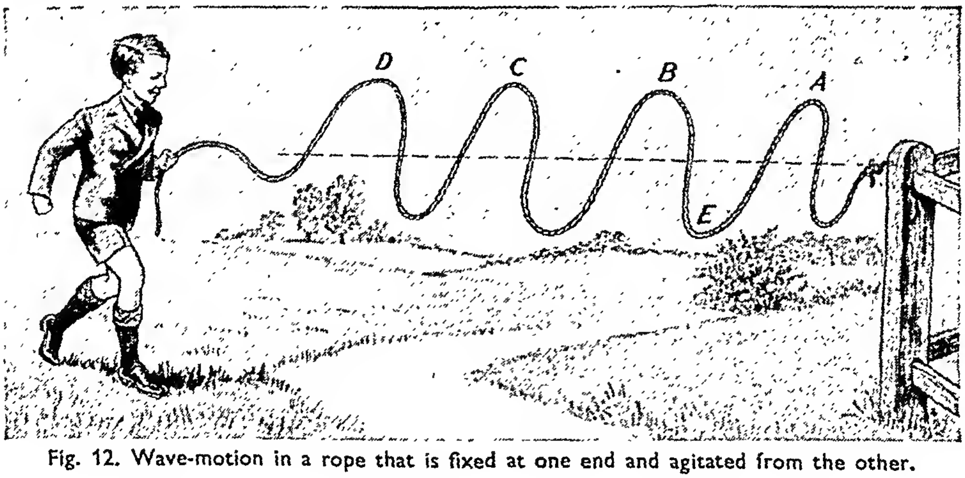


Fig. 12. Wave-motion in a rope that is fixed at one end and agitated from the other.

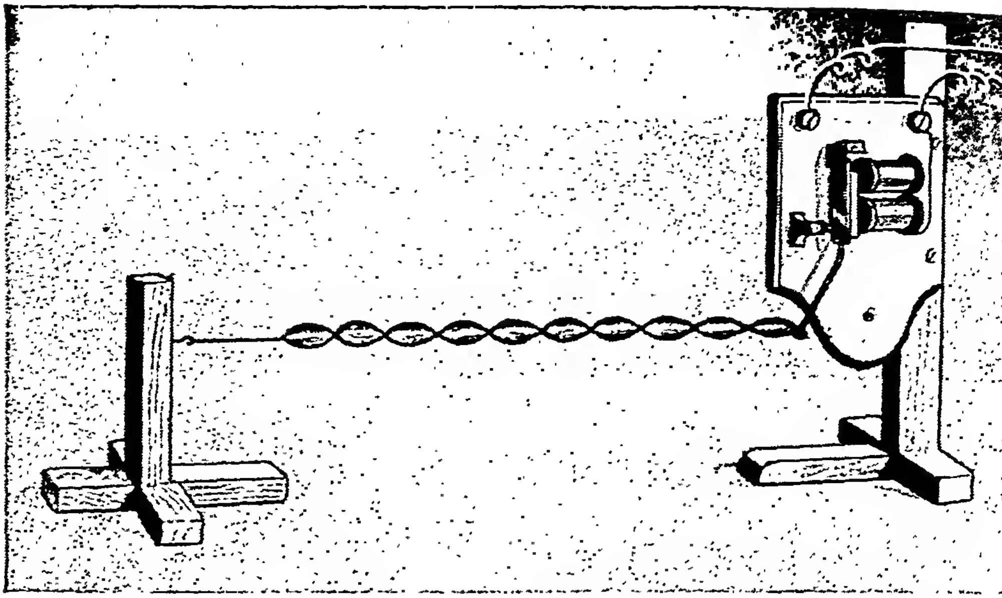


Fig. 13. A length of thread attached to the hammer of an electric-bell : regular waves are set up.

ment A–E (Fig. 12) downwards, or E–B upwards, is the amplitude. Amplitude may be said to be the greatest difference in the position of any individual particle that is oscillating in the medium transmitting the wave. It is not difficult to understand therefore, that the speed, or velocity, of a wave must be equal to the wave-length divided by its period.

All three features—wave-length, frequency, and amplitude—have a definite effect on the phenomena transmitted. Let us take the case of light, for instance, in which the amplitude determines the intensity of the light and the wave-length the colour. Here the wave-length varies over a very wide range, the shorter waves giving rise to light of a violet colour. As the wave-length increases, the colour changes by infinitely minute gradations to blue, green, and orange, until with the longest visible wave-length the colour is red. There are also other waves, both long and short, that are not perceptible to the eye, because the retina is not sensitive to them. The wave-length of the light that is perceptible to the eye varies between $\frac{1}{2,500}$ to $\frac{1}{1,340}$ millimetre. Extremely short waves cause ultra-violet light; longer waves form visible light; still longer waves produce radiant heat, and beyond these again are the Hertzian or electromagnetic waves of radio, already referred to.

The amplitude of a wave naturally changes and in time decreases, until it eventually dies away altogether. This is made clear by watching the waves from a stone thrown into water. The wave-circle increases as it spreads out from the point at which the stone entered the water, but as the energy of the original disturbance spreads over a greater length of wave, the amplitude diminishes accordingly.

Different waves require different media through which to travel. For instance, although solids will not, as a rule, transmit light waves, they will transmit various waves, such as those due to periodic compressional, torsional, or shearing stresses applied to a body. Sound-waves are transmitted by solids, liquids, or gases. Light-waves and radio waves travel through the ether. No waves ever travel instantaneously.

CHAPTER 12

HEAT

THE cause of heat was not understood until comparatively recent times. Even up to fifty years ago heat was thought to be a material substance, exactly as a light ray was thought to be an emanation of material particles. Heat was described as being "a subtle fluid, universally diffused, and capable of permeating the densest substances". The parts composing this "fluid" were supposed to be mutually repellent yet attracted by the material particles of bodies, and in this way an attempt was made to account for expansion and contraction.

We know now that heat is a form of energy. It arises from the never-stopping motion of the molecules of a solid, liquid, or gas, a motion that is additional to the movements of the constituent electrons. The faster the particles move, the hotter a substance becomes. In our next section we consider the origin of light, and we shall see that the electrons of an atom are in a perpetual state of agitation or vibration. With this vibration is associated enormous potential energy.

This kind of heat, in which the substance remains chemically the same, is not to be confused with combustion, by which fire is produced, and which involves a chemical change.

Practically all substances may be regarded as sources of heat in some form or another, particularly those bodies that are radiating light such as the stars, of which the Sun is the most important to us on the Earth.

Heat can be produced by three methods—mechanical work, chemical action, and electricity. Mechanical work produces friction and this generates heat. Friction is sufficiently powerful even to generate heat in a fluid. This we can easily prove by vigorously shaking cold water in a bottle; in about a minute the temperature of the water will have risen by nearly 1°. Even if two pieces of ice are rubbed together in a vacuum, they will generate sufficient heat to cause them to melt. It is friction that causes heat to light a match when we rub it on sandpaper or some other rough surface. If the match is rubbed on a smooth surface, such as glass, the friction is appreciably diminished and it is difficult if not impossible to strike a light. The friction in this case causes combustion, which is evidenced by the flame of the match; but there was heat before the combustion.

PRIMITIVE FIRE-MAKING

Primitive man lit his fires by friction, rubbing together two pieces of wood usually in the form of a wooden drill pressed against a sturdy wooden base. (Fig. 1).

What happens in this operation is that the strong mechanical force of the rubbing is resisted by the forces of cohesion or adhesion in the thing which is being rubbed, and this resistance generates heat. The rubbing together of wood to produce fire was followed at a much later date by the striking of flint and steel. Here the sparks are small particles of flint struck off by the metal, and raised to white heat by the friction of the impact. These white-hot particles fall on to some tinder, or some similar easily combustible material, which is then fanned into a flame. The modern application of this principle is the familiar cigarette lighter, in which the

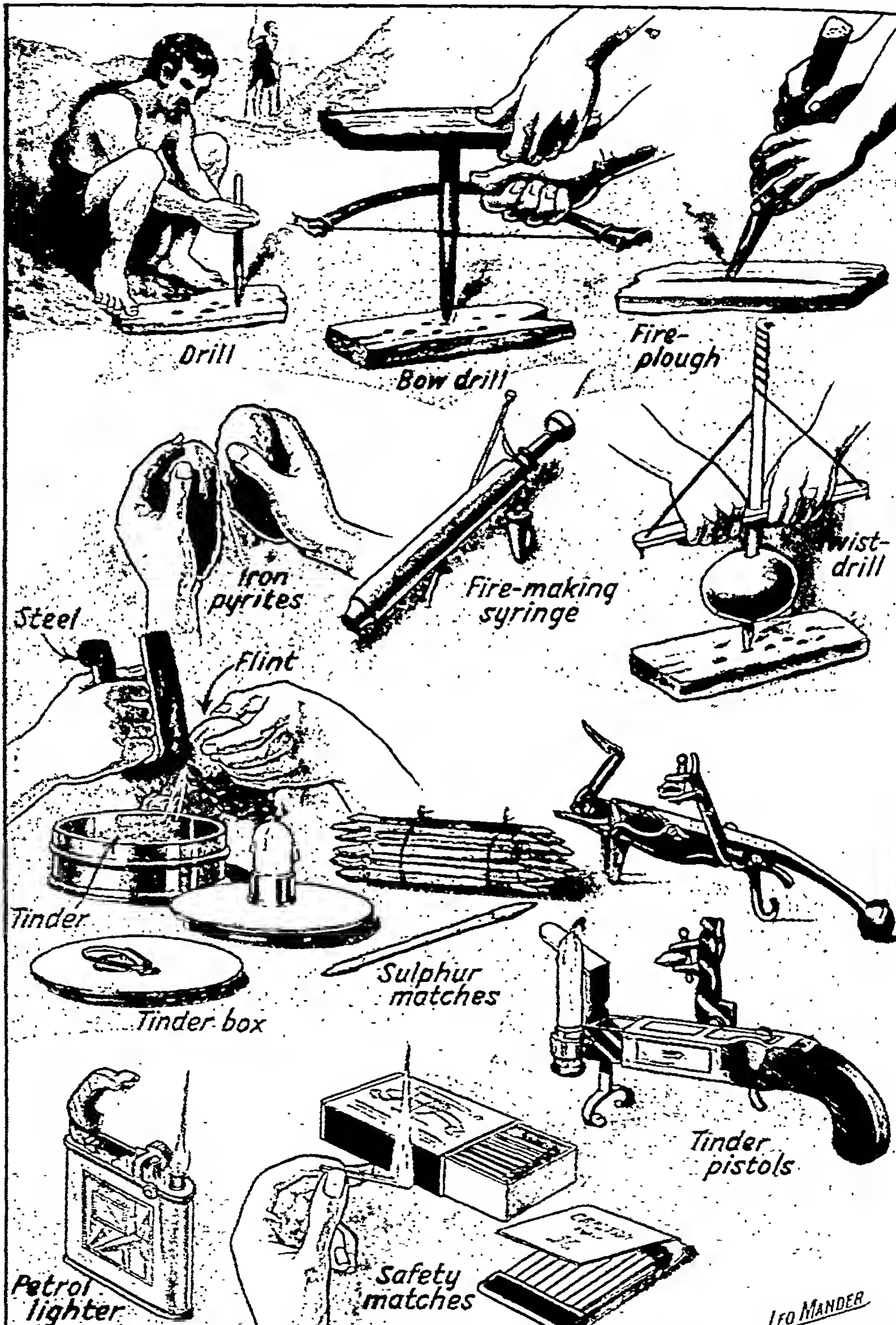


Fig. 1. Methods of fire making from the primitive rubbing stick to the modern petrol lighter

tinder is replaced with tow or some kind of cotton waste, soaked in petrol or benzine to render it easily inflammable.

Another contrivance for producing fire, used for many centuries by the natives of Burma and Borneo; is the "fire-making syringe" or "fire piston", which looks rather like a bicycle pump. A piston is moved up and down very rapidly in a dry cylinder usually of bamboo, and the compression of the air gives enough heat to light dry tinder. You have only to do the same thing with a bicycle pump, holding a finger tightly over the outlet hole, to realise how great an amount of heat can be generated in this way.

Fig. 1 shows the fire-making appliances described above.

A falling weight, or the coming together of two masses, will produce heat. For example, a pile driver at work with its hammer-blows causes the top of the wooden pile to become hot; similarly, if a nail is violently hammered it will become red hot in the very short time of two or three minutes.

HEAT AND COMPRESSION

Heat is also produced mechanically by compression. When a bar of metal is "cold-rolled", it will becomes sufficiently heated to boil water at the moment when it passes between the rollers of the rolling machine.

Heat is produced by chemical action by the combination of some such substances as oxygen and carbon. This violent heat-producing process of combination between oxygen and another substance is called combustion. The term is also extended to describe "burning" in other gases beside oxygen, but oxygen is by far the most important; oxygen combustion is the phenomenon we know as fire, which occurs in ordinary air.

In a paraffin stove, for example, the oil, which contains hydrogen and carbon, is made to combine with the oxygen in the air. When heat is applied to the wick, the heat of the flame vapourises the oil that has risen up the wick. A portion of the vapour thus formed burns (i.e., combines with the oxygen of the air) to form carbon dioxide and steam, and disintegrates the molecules of the remainder of the vapour into hydrogen atoms and particles of solid carbon. These are heated by the flame and so cause heat and a certain amount of light to be emitted from the flame.

The heat obtained is limited, however, and is proportionate to the quantities of the substances reacting on one another.

PARAFFIN GAS STOVES

A more efficient form of oil stove is the type illustrated in Fig. 2. In this stove there is no wick, the fuel being fed to the flame by means of compressed air. The stove contains paraffin in a closed reservoir fitted with an air-valve and pump.

To start the flame a small quantity of methylated spirit is placed in a cup beneath the burner and lit. As the spirit burns away, a small flame remains at the pilot light jet. The air-valve is now closed and the air pump worked a few times.

Fuel will thus be forced up into the tubes of the burner, where the heat causes it to become a gas, which leaves the burner through a small hole and is thoroughly mixed with air. This mixture of paraffin gas and air burns with a very intense flame, which makes the burner tubes still hotter, and continues to turn the fuel into gas as it passes through them.

Heat is also obtained from electricity which in its natural form—lightning—has been known to set houses on fire, melt metal rods, and fuse sand into a solid mass. An electric current flowing

Fig. 2. Structure and working of a modern paraffin gas cooking stove.

through a wire that is too fine to carry the load causes a violent motion between the molecules of the wire. Heat is developed and it may be sufficient to heat the wire red hot, as in an electric radiator, or even to melt the wire. This fact is turned to advantage in a fuse-box in which wires are arranged that will melt if the current exceeds a given value. Thus, should there be an "over-load" in the circuit due to a "short" or to some other cause, the wire fuses and the supply of current is automatically cut off from the main. This lessens the risk of fire and of damage to electrical apparatus.

Finally, there is the physiological source of heat, such as we find in our own bodies and in those of animals—both the warm-blooded and the so-called cold blooded. Both classes of animals produce heat to a very considerable extent, but the proportion of heat lost in

the cold-blooded animals is greater than in the warm-blooded. Or, to put it in another way the temperature of the warm blooded animal is fairly constant, varying within narrow limits, while that of the cold blooded animals is extremely unstable. In this lies the essential difference between them.

WHAT IS TEMPERATURE?

Temperature may be defined as the degree of hotness or coldness produced by a change in the heat energy contained in a body, occurring when no change of physical state takes place. This change is expressed for convenience as a difference in a numerical scale that has two points fixed by reference to two definite conditions of a standard substance. For most accepted temperature scales these fixed points are the freezing and boiling points of pure water at sea level.

We must clearly understand that temperature is not heat. It is a fact that a basin of cold water holds more heat energy than a teaspoonful of boiling water. True, the teaspoonful of water will scald the finger, but it does so by virtue of the fact that its molecules are in more rapid motion than those in the water in the basin, thus causing the *sensation* of temperature.

The appreciation of temperature, like astronomical mileage, is a matter of fixing a datum line according to our experience and surroundings. To us in the temperate zones, 80° F. in the shade is "hot" but to those who live in India it is "cool". The planet Mercury's temperature of 675° F. would be more than fatal to us, but it is nothing compared to the Sun's surface heat of 10,000°. And even this extraordinary temperature would be "cool" compared with the 120,000° of the stars on the edge of the planetary nebulae, with a probable 1,000,000° at their centres—figures which of course mean next to nothing to us, for they are quite beyond the ability of our mind to conceive.

Our personal sensations of temperature are often misleading, our impressions being governed moment by moment by the state of our body. Sitting in a room we may feel it cold, yet someone coming into the room after a sharp walk or some vigorous exercise may complain of the heat of the room. You may conduct an interesting experiment by taking three bowls of water, one cold, one luke-warm, and the third hot. If you hold one hand in the cold water and the other in the hot water for a few moments, and then plunge both hands into the luke-warm water, the hand that has been in the cold water will feel the luke-warm water hot, while the hand that has been in the hot water will feel it cold.

Then again, the conductive powers of different bodies mislead us. On a cold morning a poker feels cold, but a wooden chair feels comparatively warm; yet the thermometer would show that both poker and chair are at the same temperature. We are thus led to the conclusion that heat is a factor to which our senses are an unreliable guide.

HOW TEMPERATURE IS MEASURED

Temperature is measured by a thermometer (Greek: *thermos* "heat", and *metron* "measure"). The instrument, of course, is misnamed "heat measurer", for, as we have seen, it does not measure heat but temperature. Most thermometers depend for their working on the fact that a body expands when heated and contracts when cooled.

The commonest type of thermometer consists of a glass tube of a very fine and uniform bore, closed at one end and with a cylindrical bulb at the other, containing a quantity of mercury. Before the mercury is introduced into the tube

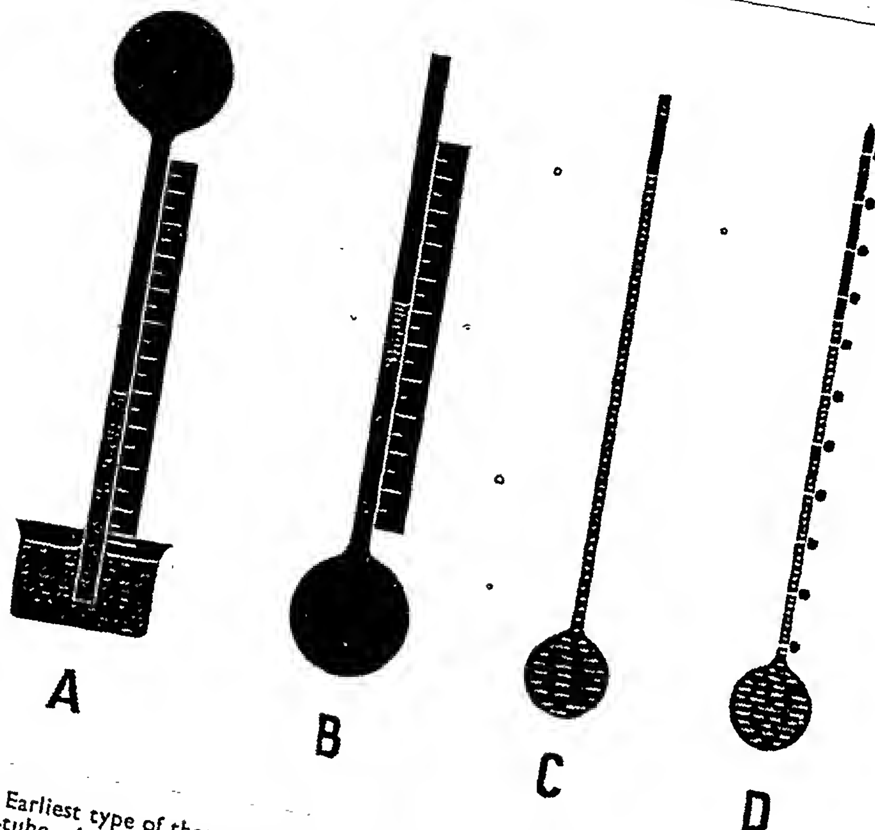


Fig. 3. (A) Earliest type of thermometer, an inverted flask in an open beaker of water. (B) The later open-tube air and water thermometer equally unsatisfactory. (C) Open-tube water thermometer. (D) First closed-tube thermometer using alcohol in place of water.

all air is expelled, the tube being then hermetically sealed and graduated with a scale. When the thermometer is brought into contact with heat, the mercury expands and rises in the tube; conversely, if it is cooled, the mercury in the tube falls. The temperature of the thermometer's surroundings is thus indicated by the position of the top of the column of mercury in relation to the graduated scale.

The thermometer appears to have been invented by Galileo—certainly he was one of the earliest to use thermometers, in 1592. His instrument (Fig. 3A) consisted of an inverted flask, the long narrow neck of which was immersed in a vessel containing coloured water. Some of the air was exhausted from the body of the flask, so that when the neck was inverted in the liquid it rose in it for a short distance. A graduated scale placed behind the neck indicated the lev of the liquid, which rose or fell the change in the temperature caused th air in the flask to contract or expand.

This type of instrument was modified about the beginning of the 17th century, the flask being no longer inverted and the vessel of liquid being done away with (Fig. 3B). A small column of liquid was held in the neck of the flask by capillary attraction. The expansion and contraction of the air in the bulb brought about by the change in temperature caused the liquid to ris

a rough measure of the amount of change to be made. There were many defects in this type of instrument, however, and an improvement was made by abandoning the use of air, the later instruments having a bulb and tube almost entirely filled with water, the top of the tube being left open (Fig. 3C).

In 1641 alcohol was used instead of water, and at some time before 1654, the closed thermometer was introduced by Ferdinand II, Duke of Tuscany. In this type, the air was expelled by heat and the tube containing the alcohol was sealed at the top (Fig. 3D) The tube was graduated by placing the zero mark at the level indicated by the liquid when the instrument was placed in a certain cellar in Florence in winter. In the following summer the instrument was again placed in the same cellar, the reading then being marked "10", and the space between it and zero being divided into equal parts.

This method of calibration was soon found unsatisfactory, for the cellar temperatures of course varied in different years. It was then that the melting point of ice was taken as giving a more constant zero, and it was adopted as a uniform standard. A further step was made when Amontons found that the boiling point of water was also constant, and that too was adopted as standard.

In 1714, G. D. Fahrenheit, an instrument maker of Amsterdam, introduced the use of mercury in thermometers and revised the scale used in calibration. For his scale Fahrenheit chose as zero the temperature of a mixture of ice and salt, which is colder than pure ice; and for the higher fixed point he chose the temperature of his body, calling it 96°, which is a conveniently divisible number. This gave him freezing and boiling points of water as 32° and 212° respectively, separated by 180 divisions of the scale.

Six years after Fahrenheit's death (in 1736) the centigrade scale was introduced by Anders Celsius of Upsala. As its name indicates (Latin, *centum* "a hundred", *gradus* "steps") the centigrade thermometer is graded to 100°. In calibrating a centigrade thermometer the bulb is immersed in a mixture of ice and water and the position to which the

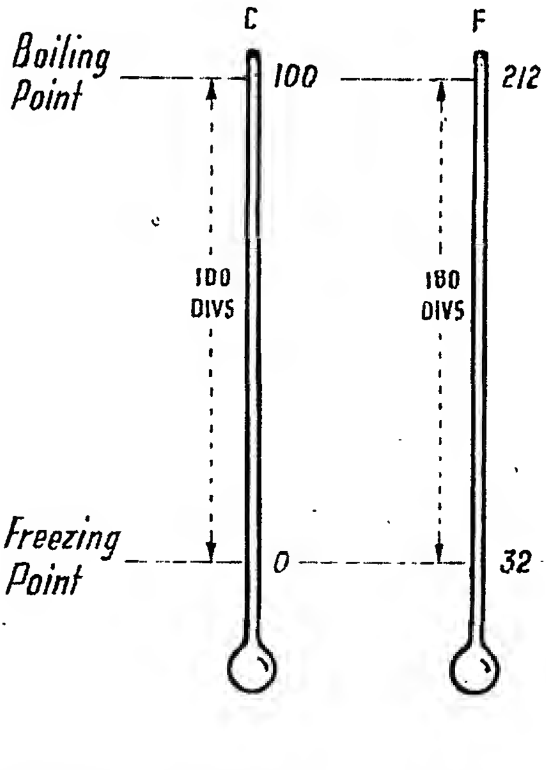


Fig. 4. Centigrade (left) and Fahrenheit (right) Thermometers

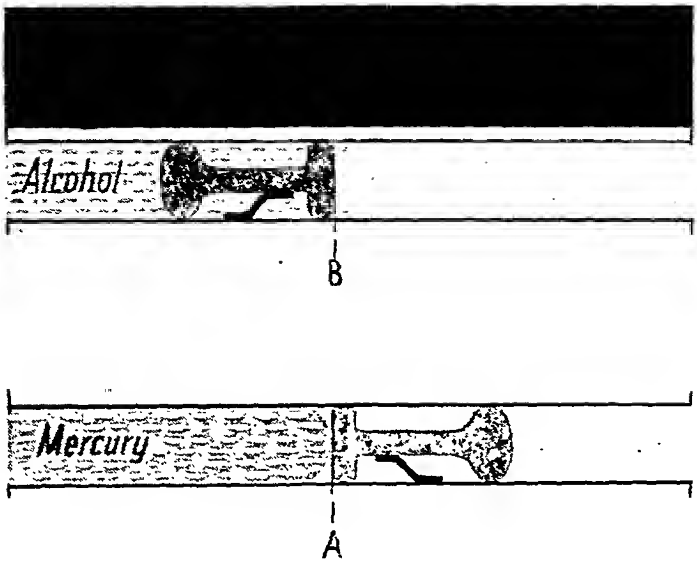


Fig. 5. One form of self-registering device in minimum (top) and maximum (bottom) thermometers. Note the concave meniscus at B and convex meniscus at A (For explanation see text).

The best substance to use in a thermometer is one that expands to the greatest degree for any given rise in temperature. The most convenient substance for everyday use is mercury, for it is regular in its expansion and remains liquid at ordinary low temperatures, its freezing point being $-39{\cdot}1$°F. Mercury thermometers are in general use to measure temperatures from about -40°C. to 330°C. Spirit thermometers are sometimes used, the spirit being coloured black or red. This type of thermometer is sometimes preferred because of the greater visibility of the column of spirit as compared with a column of mercury.

mercury sinks is marked "o" or zero. The bulb is then placed in a jet of steam from boiling water and the point to which the mercury rises is marked 100 the intervening space between o and 100 being divided into equal parts.

FAHRENHEIT AND CENTIGRADE

Both Fahrenheit and centigrade scales are in general use; when stating a temperature it is customary to indicate which scale is used by writing F. or C. after the figure, for a degree in the former represents a lesser difference of temperature than a degree on the latter (Fig. 4). Obviously 1°F. equals only $\frac{5}{9}$°C. and conversely 1°C. equals $\frac{9}{5}$°F. It is useful to know that we can convert centigrade to Fahrenheit by multiplying the reading by 9, dividing the result by 5, and adding 32. On the other hand, to convert Fahrenheit to centigrade we subtract 32 from the reading, multiply by 5, and divide by 9. Thus:

(1) $50°\text{C.} \times 9 = 450 \div 5 = 90 + 32 = 122°\text{F.}$
(2) $122°\text{F.} - 32 = 90 \times 5 = 450 \div 9 = 50°\text{C.}$

Where it is desired to measure very low temperatures, alcohol or toluol are used instead of mercury. As the expansion of gases is considerably greater than that of liquids, gas can be used to indicate temperatures. Gas thermometers, however, are only used for certain scientific measurements.

Self-registering thermometers are those that record the maximum and minimum temperature readings during the day or night, as may be required. They do this by an ingenious arrangement. In some types of maximum thermometers a small shaped piece of steel is introduced into the tube above the mercury. In some cases it has a spring that presses against the inside of the tube and so retains the index in position (Fig. 5). Thus, on a rise in temperature, the index is pushed up the tube. When the temperature falls it

remains behind, and thus indicates the maximum height to which the mercury has risen.

The minimum thermometer uses alcohol and here again a steel index is used (Fig. 5A). The liquid has a curved meniscus and surface tension drags the index back with the liquid when the temperature is lowered. When the temperature rises the index is left behind, so recording the lowest temperature reached during the required period. In both cases the indexes are usually reset by being drawn along the tube with a magnet.

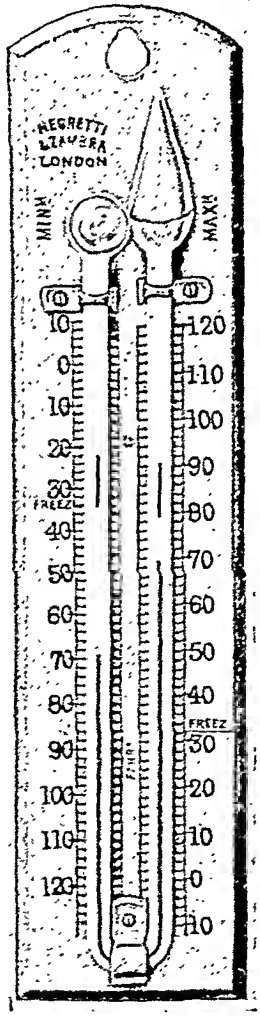


Fig. 6. Self registering minimum and maximum thermometer.

A common type of combined maximum and minimum thermometer is shown in Fig. 6. The left-hand round bulb is the thermometer bulb proper, and contains spirit. The darker substance in the bend of the tube is mercury, and the temperature is indicated on each of the two scales by the ends of this mercury column. The two index pieces can be clearly seen, and it is obvious that the left-hand index will mark the minimum temperature and the right-hand index the maximum in the way already described for simple maximum and minimum thermometers. There is a vacuum inside the right-hand pointed bulb on the maximum side.

Nearly a century ago (in 1842) Dr. J. R. Mayer, of Heilbronn, heated to double its volume a cubic foot of air under ordinary atmospheric pressure. He showed that in this experiment a certain amount of work must have been produced, since the air had been made to expand against the normal atmospheric pressure. As we have seen, this pressure is about 15 lbs. to the sq. in., so that in the experiment the pressure on one sq. ft. was 2,160 lbs. Thus Mayer showed that in doubling the volume of the cubic foot of air the heat must have raised a weight of 2,160 lbs. through a height of 1 ft.

At about the same time J. Prescott Joule, of Manchester, experimented on the subject of the work done by heat, but arrived at his conclusion in an entirely different manner.

He used a falling body, the motion of which was communicated to a spindle wheel that was caused to revolve as the weight descended (Fig. 7). The motion received by the spindle was used to produce friction by causing paddles to revolve in a liquid—either water or mercury. The liquid, the temperature of which was carefully measured, was enclosed in a circular vessel insulated from any outside differences in temperature. The friction of the revolving paddle caused an increase in the temperature of the liquid, and this was accurately measured with an extremely sensitive thermometer. Joule showed that to evolve the quantity of heat that was capable of increasing the temperature of 1 lb. of water by 1°F. required the expenditure of a definite mechanical force, the degree of which is now determined to be equal to the fall of 778 lbs. through 1 ft. Con-

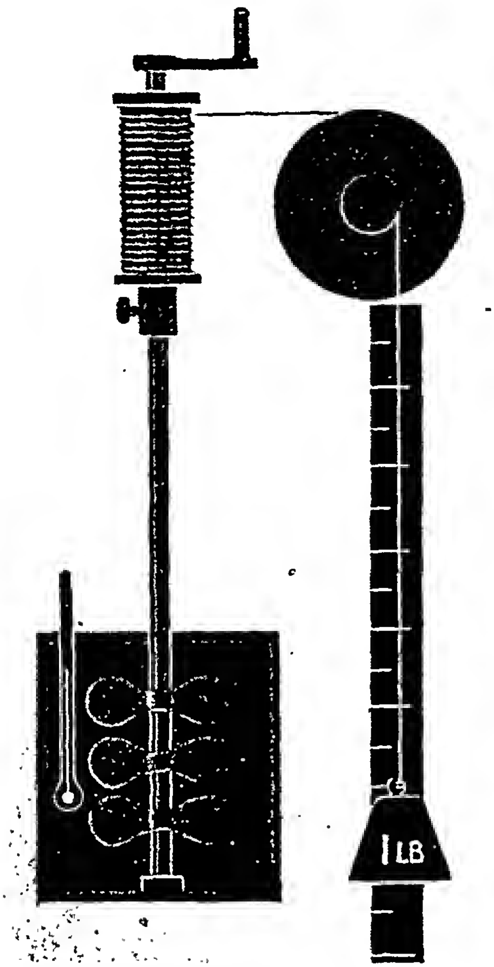


Fig. 7. Joule's experimenr in diagrammatic form (for explanation see text).

versely, the energy required to raise 1 lb. of water 1°F. would lift a 1 lb. weight to 778 ft. The unit of work done in lifting 1 lb. one foot is called a "foot-lb." The amount of work required to raise 1 lb. of water 1°F. is thus 778 foot-lbs.

Joule's "mechanical equivalent of heat" experiment not only proves the direct conversion of the movement of a tangible mass—mechanical work—into the motion of intangible heat, but gives the exact relative value of the respective units.

Incidentally, one may ask, how do we explain the apparent contradiction that when Joule stirred water with paddles it was heated, whereas when we stir a cup of tea we cool it? The answer is that the work done in stirring tea is so very minute that no appreciable heat is generated. On the other hand the stirring is constantly bringing fresh parts of the hot tea into contact with the cold air, hence the tea cools more quickly. In Joule's apparatus, the vessel containing the liquid was insulated against any such escape of heat.

So far we have considered only changes of temperature or the *intensity* of hotness or coldness. Let us see, now, how this is related to the *quantity* of heat, which is a very different subject since a small amount of heat may be made to produce a high temperature.

CAPACITY FOR HEAT

No two substances of the same mass get hot at the same rate. Different substances require different quantities of heat to raise their temperatures or, as it is said, they have different capacities for heat. Similarly no two substances cool or lose heat at the same rate, and this can be demonstrated by a simple experiment. If balls of iron, copper, zinc, and lead are all heated for the same length of time at the same temperature and placed on a slab of wax, they will sink into the wax, giving off heat and so melting the wax. They will sink to different depths, because of the different quantities of heat given off by each. The iron ball sinks the deepest and the others less, the lead ball least of all (Fig. 8).

The *quantity* of heat—as distinct from the temperature—may be measured by an apparatus called a calorimeter. The results are expressed in "calories", a calorie in the metric system being the amount of heat required to raise by 1°C. the temperature of 1 gram of water at

4°C. The British system is based on the amount of heat that is required to raise 1lb. of water at 39° F. by 1° F. This is called the British Thermal Unit and it is equal to 253 calories. The calorie is the unit generally used in scientific investigations whilst in engineering the British Thermal Unit (abbreviated B. Th. U.) is employed.

HOW HEAT TRAVELS

Heat travels in straight lines—as light does—and is radiated from all bodies, its intensity decreasing inversely as the square of the distance from the source. Thus a thermometer that rises a certain number of degrees at 1 in. distant from a source of heat will rise a quarter of the number of degrees at 2 ins., a ninth of the number at 3 ins., and so on.

Heat may be reflected, following the same laws of reflection as sound and light, the angle of reflection being equal to the angle of incidence. This has already been explained in connection with Sound. Like light, heat may be focussed, and in the parabolic reflectors of modern household electric fires we have a concentration of rays into parallel beams, in the same way as light rays are focussed in motorcar head lamps (Fig. 9).

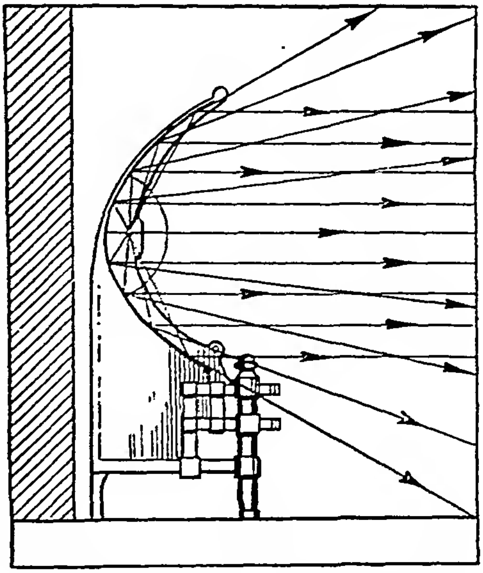


Fig. 9. Heat, like light, can be focussed. This figure illustrates the parabola-shaped reflector of a modern electric radiator.

It is only during the last 150 years that a method has been found to turn heat into work by means of the steam engine, and more recently by the internal combustion engine: as ordinarily used in petrol-driven motor cars.

In the common steam engine we obtain heat by the combustion of coal with air. These "burn", so giving out hot gasses, as we call the assemblage of violently-moving molecules. They in turn agitate the molecules of water within. The agitated molecules of water fly off as a steam and jostle

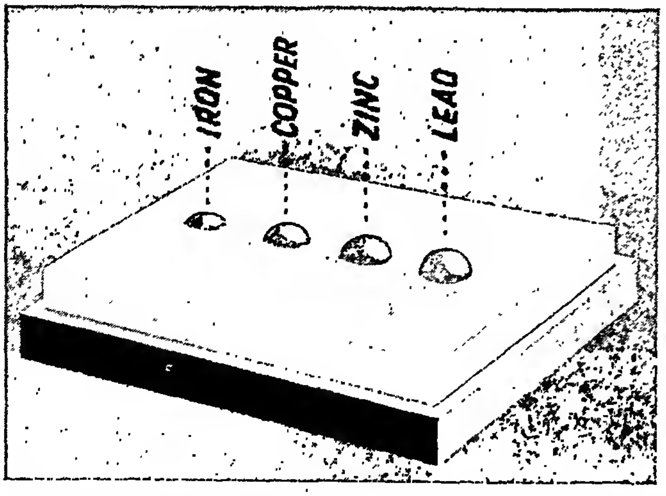


Fig. 8. Balls of iron, copper, zinc and lead heated for the same length of time at the same temperature and placed on wax, sink to different depths because of the different quantities of heat given off by each. The iron ball sinks deepest: the lead least.

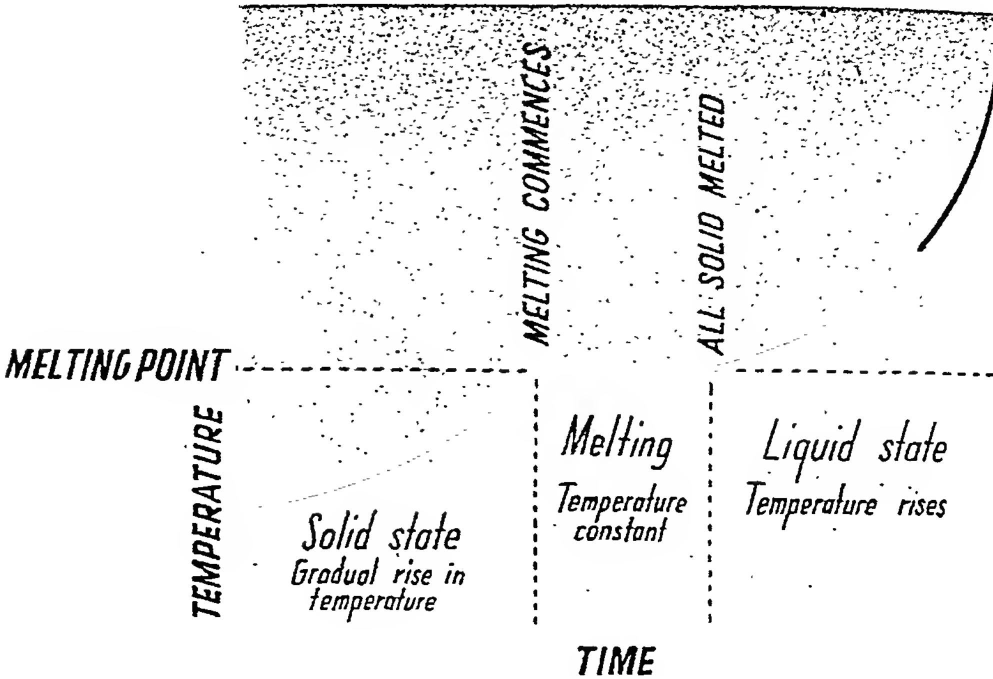


Fig. 10. Illustrating the principle that heat may be absorbed without any change of temperature.

against a piston pushing it forward, so driving a crank and turning a flywheel.

We see, then, that the application of heat to a substance speeds up the molecules in it. In the case of a solid, if the application be continued, the molecules go on vibrating more and more rapidly. Ultimately, the vibration becomes so violent that the molecules lose their grip on each other, resulting in the crystals breaking down so that the solid substance becomes a liquid.

WHAT "MELTING POINT" MEANS

The change from a solid to a liquid occurs at what is called *melting point*, and the thermometer shows that the steady rise in temperature that has occurred whilst the heat is applied is halted at this point. The rise in temperature due to the heat does not go on indefinitely, a stage being reached when the mercury in the thermometer is stationary and when the temperature ceases to rise. This is the melting point, and at this the thermometer will remain stationary as long as there is still any solid left unmelted. Immediately all the solid is melted, however, the temperature commences to rise again (Fig. 10).

The range of melting points of solids is a very wide one. At one end of the scale is helium, which melts at −272°C.; and at the other end is carbon, melting at 3,500°C. Helium is a remarkable element. Its atoms are so light in weight and so perfectly balanced that the slightest extra motion imparted by heat is sufficient to make them lose their grip on one another so that the solid form becomes liquid. This is the reason why the solid melts at less than 1°C. above absolute zero, at which point every atom and molecule is motionless. To show the wide range of the melting points of other substances we give the following examples: benzine, 7°; tallow 33°; paraffin wax, 54°; sulphur, 114°;

zinc, 420°; aluminium, 657°; silver, 954°; gold, 1,001°; copper, 1,100°; cast iron, 1,200°; and platinum, 1,900°C.

Ice melts at the very definite temperature of 0°C. Even at $\frac{1}{1,000}$° above 0°C. it is a liquid. Thus freezing point *is* actually a "point" on the thermometer scale and not a range of a few degrees round about 0°C.

WHY ICE MELTS SUDDENLY

Although ice melts thus suddenly, other substances do not melt as suddenly. The reason for this is not difficult to understand. Ice melts at this critical point because it is a pure substance; other pure substances melt as sharply as ice. On the other hand, impure substance, or mixed substances, melt gradually. For instance, butter, which is a mixture of different fats that themselves melt at varying temperatures, has a wider melting point because those of its components with low melting points naturally melt first. That is why butter melts only gradually, and why on a hot day we get soft butter.

This property of impure substances is used in many ways in industry, as when the plumber "wipes" a joint in a pipe. At 327°C. pure lead is a solid, but at 328° it is a liquid. The margin of 1° is too fine for working on normally, so joints cannot be made with it. Tin is equally unsatisfactory, for it is a solid at 231°C. and a liquid at 232°. Mixing lead and tin in equal parts, however, gives "plumber's solder", an alloy that begins to solidify at 220°C. but is not hard until its temperature is 180°C. This gives the plumber a sufficient margin of time to "wipe", or make, his bulbous joint, as we see it below the domestic wash basin or at the joint of the tap in the water pipe.

Boiling, or the change of a substance from a liquid to a gaseous state, takes place through the mass of a liquid as soon as the whole reaches *boiling point*. The boiling-point of a liquid is the temperature at which the tension of its vapour exactly balances the pressure of the atmosphere. At that point the liquid assumes a state of constant agitation or "ebullition" by the formation of bubbles of vapour. As long as there is any of the liquid that has not boiled, the temperature of the whole remains constant, and this is said to be the boiling point of the liquid.

A liquid approaching boiling point is said to "simmer" or a kettle to "sing". This is due to the innumerable bubbles of rapidly forming gas that rise to the surface and burst.

We have already learned that air has weight, and that therefore it exerts a pressure that is greatest at the Earth's surface because the air is densest there by reason of the weight of the whole of the atmosphere above. Because of the inherent property in a gas of transmitting pressure equally in all directions, and because the air is composed of gases, atmospheric pressure is equal on all objects. That is to say, instead of the pressure being all on the roof of a house, as it might be were the law of pressure otherwise, actually the pressure is equal on the roof, walls, and floors of a house and inside as well as outside. At sea-level under ordinary conditions atmospheric pressure amounts to nearly 15 lbs—actually 14·73 lbs.—to the square inch.

PRINCIPLE OF THE BAROMETER

As we rise above sea level the pressure decreases, and, as we have seen, it is on this fact that the principle of the barometer depends. The column of mercury is held in position entirely by the pressure of the atmosphere, so that if the atmospheric pressure increases, the mercury will be forced higher in the tube; if it decreases, the height of the mercury will be lowered

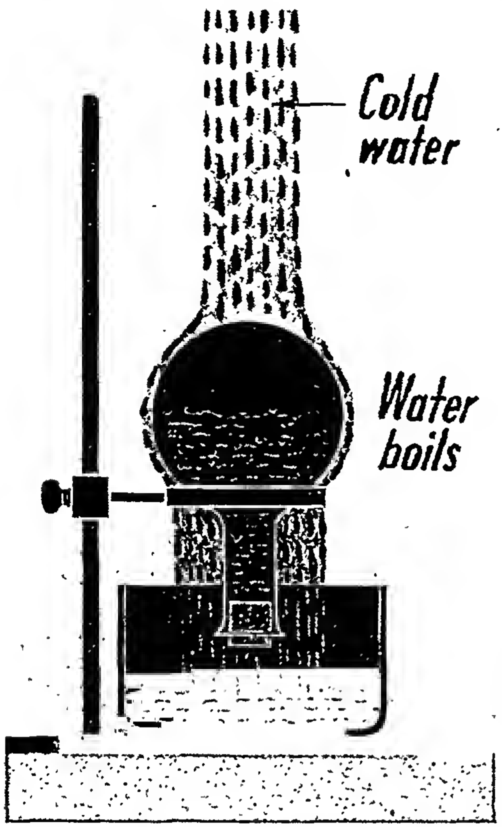


Fig. 11. The effect of pressure on the boiling point of water (for explanation see text).

Now, a variation in atmospheric pressure also affects the point at which liquids will boil. At sea level water will boil at 212°F., but as the altitude increases and atmospheric pressure becomes less, the boiling point becomes lower. This can be shown experimentally by half filling a flask with hot water and corking it. The flask is now inverted and cold water poured over it. This causes the heated air to cool and as the pressure is diminished the water commences to boil (Fig. 11).

As a rule when heated in a vacuum, liquids will boil from 60° to 140° lower than their ordinary boiling point. This fact is used in the manufacture of certain medicinal preparations, the properties of which would be destroyed if they were exposed to the normal boiling point of water at sea level: that is 212°F.

Generally speaking the boiling point decreases by 1°F. for every 596 ft. increase in altitude, so that at the summit of Mount Blanc (15,781 ft.) water will boil at 185°F. This has nothing to do with the temperature of the atmosphere for it is as easy to boil water at sea-level in the Arctic as it is at sea-level in the tropics. On the other hand, the rarefied air at high altitudes makes it very difficult to obtain sufficient heat to boil water even at the lower temperatures required. For this reason, in the higher alititudes—as in the plateaux of the Andes, for example—all food is roasted or baked; boiled eggs are unknown! At the St. Bernard Hospice (8,600 ft.) the monks prepare fried or roasted food rather than have boiled dishes.

BOILING POINT BELOW SEA LEVEL

Correspondingly, an increase in pressure causes an increase in the boiling point. In mines and valleys below sea-level water will not boil at 212°F.

The temperature to which a substance may be heated under pressure is limited only by the strength of the vessel in which it is contained. This fact is used industrially, as for instance preparing gelatine from bones by heating them under pressure to a temperature considerably in excess of 212°F., so easily separating the gelatine from the unrequired material. The bones might be boiled for a long period under ordinary pressure at this temperature without the desired effect taking place.

Another consideration affecting boiling point is the *nature* of the vessel used. Water boils at 212°F. in a metallic vessel, but in a glass vessel a temperature of 214°F. is necessary. If the vessel used is varnished inside with shellac, the temperature may be raised to 220°F. without ebullition taking place.

Experimentally, the temperature of

water may be raised to some degrees above boiling point and the liquid will resist boiling, owing to the natural tendency of the molecules to resist by cohesion the change from a liquid to a solid state. If a bubble of air or stream be introduced into such superheated water, however, the delicate balance is upset, cohesion is ended, and ebullition immediately commences.

DIFFERENT BOILING POINTS

Different liquids have different boiling points because of their different chemical constituents. As in the case of melting points, these boiling points show some extreme differences of temperature. Hydrogen boils at −253°C.; chlorine at −34°; chloroform, at 61°; benzine, at 81°; water, at 100°; turpentine, at 157°; paraffin, at 280°; linseed oil, at 315°; mercury, at 357°; sulphur, at 445°; silver, at 1,955°; iron, at 2,450°; and carbon at 4,200°C.

That "freezing" and "boiling" points on a thermometer scale are purely relative terms, fixed with reference to water merely for purposes of standardisation, will at once be realised when we learn that a kettle containing liquid air will quickly come to the boil *if placed on a block of ice!* (Fig. 12). The reason is that the ice is intensely hot as compared with the extremely low temperature of the liquid air. Another example of this curious state of affairs is afforded when steel liners for motorcar cylinders are dipped into liquid oxygen to shrink them in position. The oxygen immediately begins to boil, and continues to do so until the steel is at the same temperature as the oxygen. The effect is similar to dipping a red hot poker into a bucket of water, except that the contrast of temperatures between the oxygen and the steel is much greater than that of the poker and the water. Liquid oxygen cannot be touched by hand, for it would result in a more severe "burn" than if a bar of red hot iron were touched. A red hot bar of iron burns the hand because of the enormous amount of heat transferred to the flesh, whilst liquid oxygen "burns" because of the heat it takes away.

This difference in the relative condition of things is again illustrated by oxygen, which in a normal atmospheric state at normal temperatures is a gas. Under similar conditions, water is a liquid. To turn the water into a gaseous state we have to raise the temperature, and to turn it into a solid we have to reduce the temperature. If it was normal for water to be vaporised at ordinary temperatures, to obtain it in a liquid form the temperature would have to be reduced until at a certain point the vapour started to condense, then boil, and then liquefy. In the factories that are concerned with extracting oxygen and other gases from the air, the temperature is lowered, causing the gases to boil, liquefy, and finally—if the temperature is reduced sufficiently—to become solid.

A vapour can be converted into a liquid by cooling it, this being the

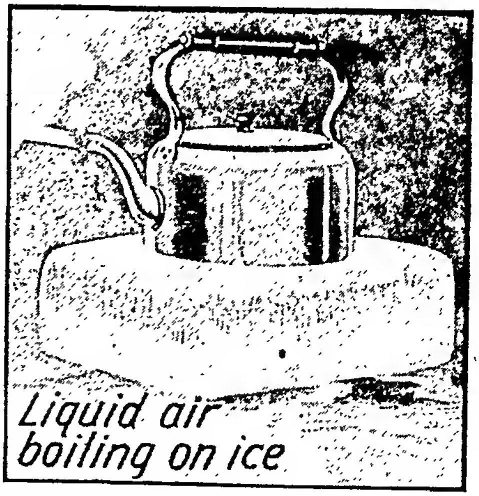


Fig. 12. Liquid air is so cold that it would boil if placed on a block of ice.

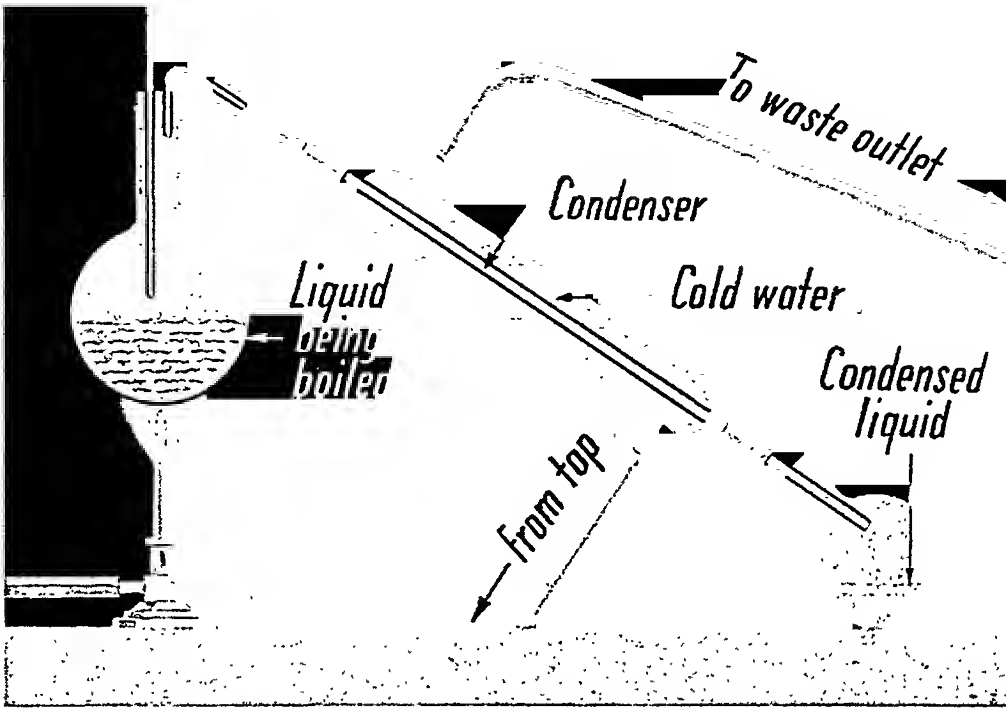


Fig. 13. The principle of condensation. Water is boiled in one flask and the steam in passing through a tube surrounded by cold water is condensed back into water. Fresh water can be obtained from sea water, and many other liquids can be purified or distilled, in this way.

opposite process to converting liquid into vapour by heat. This process of *condensation*, as it is called, is used for the purification or distillation of water and other liquids by means of a still. It is materially assisted by the fact that different liquids have different boiling points, for this enables mixtures of liquids to be separated or purified by distillation. For instance, it may be desired to separate an odorous liquid or perfume, which is a volatile oil, from the alcohol or ether used as a solvent. The liquid to be separated is converted into vapour and this is cooled by circulating cold water around the pipes in which it is carried (Fig. 13). If there are any solids in the mixture they remain behind, as they are not converted into vapour.

These odorous liquids are obtained from various parts of plants, such as fruits, leaves, petals, etc. In the case of some fruits, as for example lemon and orange, the oil is secreted in tiny sacs. In some cases it is obtained by pressing it out of the peel. In others the leaves are distilled with water or steam. Oils secreted in the petals of the flowers are sometimes obtained by the process of *enfleurage*. The petals are allowed to remain in contact with thin layers of lard smeared over sheets of glass. The lard dissolves the oil, and this is eventually removed by shaking the lard with alcohol and then distilling.

Volatile oils owe their aroma to a number of constituents, all of which contain oxygen. They may be what the chemist calls alcohols, aldehydes, ketones or esters—compounds of alcohols with an organic acid. There is, in addition, a high percentage of some substances that have no real aromatic value. Such substances are non-oxygenated, con-

sisting of carbon and hydrogen only, and are known technically as terpenes and sesquiterpenes. These substances are removed from volatile oils because it is found that their removal results in an oil, known as a terpeneless oil, which is more concentrated, has better keeping properties, and is also more readily soluble in alcohol, and therefore of great importance in perfumery.

A new method of depriving oils of their terpenes, recently patented, consists of agitating the oil with two immiscible solvents. One dissolves the terpenes and the other the oxygenated odoriferous portion. The material is allowed to separate into its two layers, each of which can be distilled, under reduced pressure, to recover the odorous and non-odorous portions respectively. (The principle of distillation under reduced pressure is illustrated in Fig. 14). The feature of this process is that it can be carried out at comparatively low temperatures. The apparatus consists of a tube about 6 ft. in length and 2 in. in diameter. The oil is fed in the middle, and the solvents one at each end. Baffles of gauze separate the tube into a series of mixing spaces provided with mechanical stirrers and settling chambers from which the two solutions can be tapped.

If it is desired to separate two liquids, the one with the lower boiling point is condensed and collected first, that of the higher boiling point being left behind.

USE OF DISTILLATION

Distillation is used not only in the laboratory but in many processes in industry, as in the preparation of alcohol, benzol, and so on. Crude petroleum contains many valuable oils with different boiling points—naptha and petrol are light oils, oils used for lubrication are

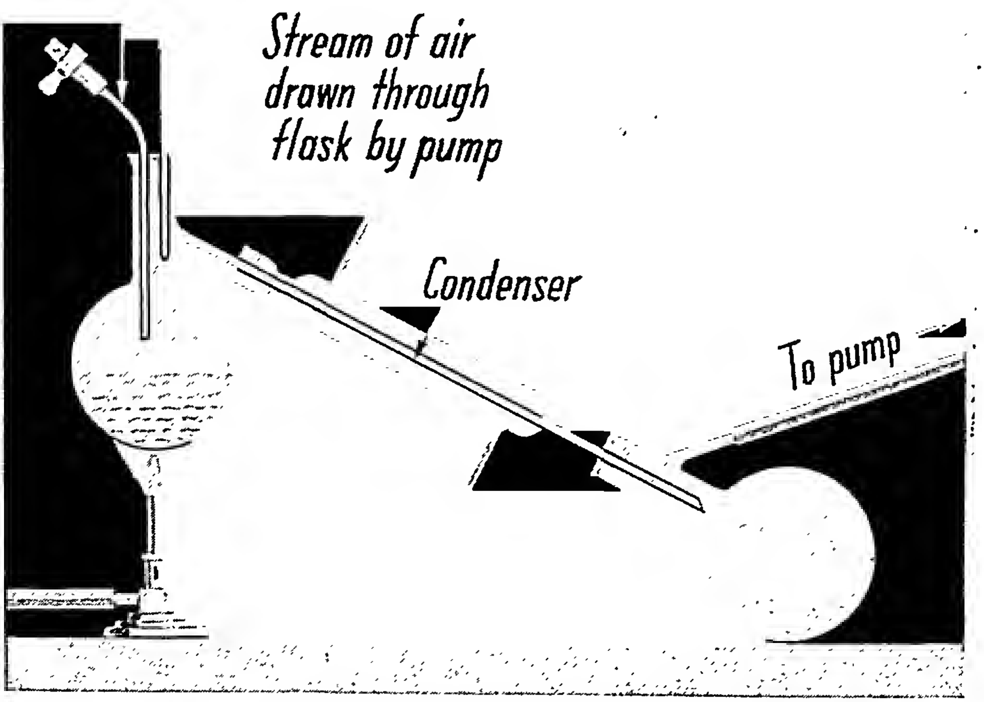


Fig. 14. The principle of distillation under reduced pressure or in a vacuum (see text).

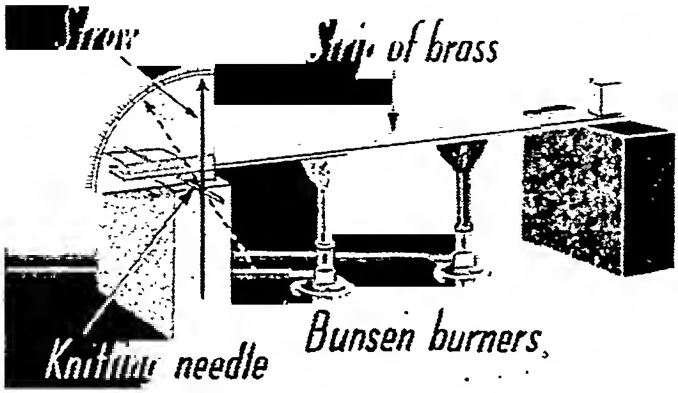


Fig. 15. Experiment proving that solids expand under the influence of heat. A full explanation is given on this page.

heavier, and then come paraffin-wax and vaseline—all of which are separated from the original mixture by distillation. Gases may also be purified by cooling with liquid air the consequence that they liquefy and can be distilled.

If the temperature is low enough the molecules of a solid re-arrange themselves in crystalline order, and as this happens certain changes take place that enable the process of crystallisation to be used in industry for obtaining a pure element from a compound. This process is based on the fact that substances dissolve to a different extent in water, which makes it possible to recover one as a pure crystal, and to leave the unwanted substance in solution.

It is by a similar process that radium is obtained, but in this case the process is a very lengthy one. The minute amount of radium that can be recovered from a ton of ore is only about ten milligrammes, a milligrame being a thousandth of a gramme. This is equal to ·0154 grains. To put it in another way, five of them would weigh the same as a very small drop of water! Radium is exceptional, however, for most substances—such as salt, sugar, soda, quinine, etc. —are easily purified. In working in large quantities, a hundred gallons or more liquid may be dealt with at once, the process generally requiring about two or three days for completion.

Except in a few cases all bodies expand when heated and contract when cooled in dimensions of line, area, and volume. This holds good for all three states of matter —solids, liquids and gases. We can demonstrate this by experiment.

EXPANSION OF MATTER

The first experiment demonstrates the expansion of solids. One end of a metal bar is fixed so that it cannot move and the other is supported on a block of wood. Between the wood and the bar is a knitting needle, with a straw to act as a pointer, as shown in Fig. 15. If a bunsen burner or methylated spirit lamp is placed beneath the metal bar it will be found to expand when the heat is applied, the expansion causing the pointer to move as shown in the diagram. Fig. 16 shows another way in which the expansion of solids can be demonstrated.

A second experiment will illustrate the expansion of a liquid when heat is applied to it. A flask with a tube passing

Fig. 16. A metal ball that, when cold, will just pass through a ring, will not do so when heated

through a cork is filled with water until the level of the liquid reaches the top of the flask. The flask is then placed in a vessel of hot water, and the water in the flask will be seen to rise up the tube (Fig. 17, left). As soon as the source of heat is removed and the flask is allowed to cool, the level of the liquid falls again.

The expansion of gases on the application of heat can be shown by partly filling a flask with water and fitting a cork and glass tube in such a way that the bottom of the tube is below the surface of the water. The flask is then held in the hand. The heat causes the air in the flask to expand, thus forcing the water up the tube (Fig. 17, right). Another experiment to show the contraction of a gas on cooling may be carried out by thoroughly warming an empty flask over a flame. When this has been done the flask is inverted and its neck placed in a vessel of cold water. As the air in the flask cools, the water rises to a considerable distance in the flask. This is due to the fact that the gas (air) in the flask expanded when heated, the surplus being forced out of the flask. When the flask was allowed to cool, the pressure of the air in it decreased. As this pressure became less than the normal atmospheric pressure exerted on the level of the water in the vessel, the equilibrium—the balance of the normal pressures—was disturbed. To restore the equilibrium, the water was forced up the neck of the flask until the pressure inside the flask was equal to the atmospheric pressure outside it.

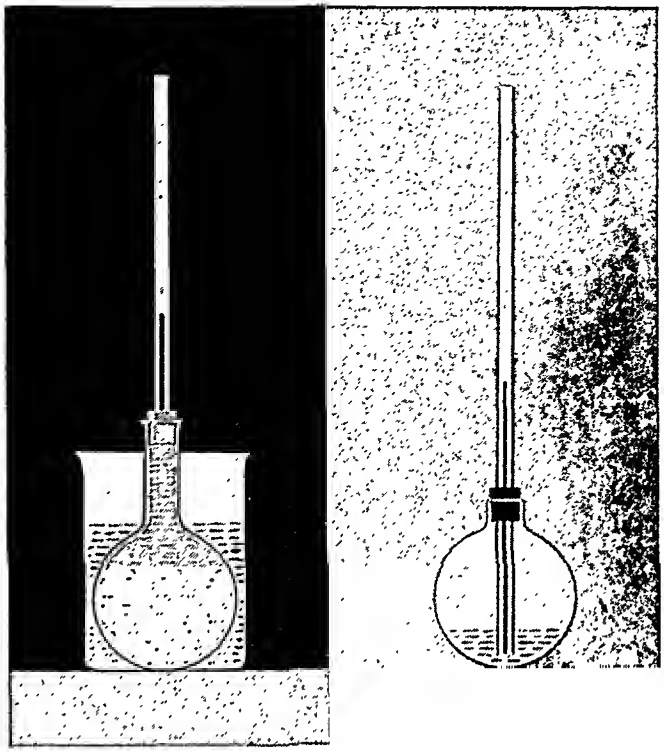


Fig. 17. (Left) Expansion of Liquids. The water in a flask placed in a beaker of hot water, rises up the tube. (Right) Expansion of Gases. If a flask partly filled with cold water is held in the hand, the heat makes the air inside expand, forcing water up the tube.

WHAT CAUSES EXPANSION

The expansion of bodies when heated is due to an increase in the motion of the molecules of which they are composed. What actually happens is that the motion of the molecules is speeded up by the heat—they are given more energy, as it were. Consequently, they tend to move in larger orbits and thus require more space. Alternatively, when the temperature is lowered, substances contract because the motions of the molecules are slowed down, and as their orbits are correspondingly reduced they require less space.

Although a given substance will

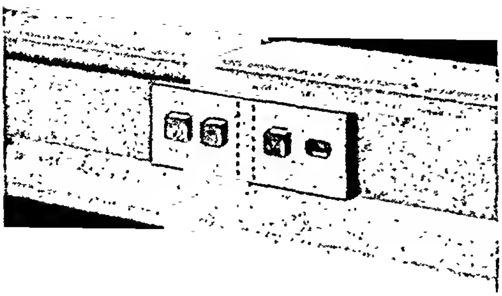


Fig. 18. Expansion in solids. The rails on a railway line have gaps between them joined by fish plates to allow for expansion in hot weather. These are called expansion joints.

always expand to practically the same extent for a given increase in temperature, the amount of expansion differs with different substances. This is due to a different degree of attraction between the molecules of which they are composed. In those substances where this attraction is greater, obviously the molecules will find it more difficult to increase the size of their orbits than in the case of those molecules in which the attraction is less intense. Consequently, in such substances the rate of expansion will be less for the application of a given degree of heat.

The amount of expansion in length of a substance due to rise in temperature is called the *coefficient of linear expansion.* This is expressed in unit lengths per unit rises of 1°C. Actually, the amount is very small, as will be seen from the following examples: lead, 0·000029; aluminium, 0·000023; silver, 0·000019; brass, 0·000018; copper, 0·000017; iron and steel, 0·000012 ft. Thus, if 1 ft. of iron is heated 1°C. its length will increase 0·000012 ft.; if it is heated by 10°C. its length will increase 0·000012 × 10, so that it will then be 1·00012 ft. long.

If the Fahrenheit scale is used instead of centigrade, the coefficient of linear expansion per 1°F. will be $\frac{5}{9}$ that of the centigrade scale, because 1°F. is equal to $\frac{5}{9}$ of 1°C.

As a body expands in all directions when heat is applied to it, there are also coefficients of surface expansion and coefficients of volume expansion. These coefficients are really of greater importance than that of linear expansion. As we might expect, the coefficient of surface expansion is twice that of linear expansion, whilst the coefficient of volume expansion is three times that of linear expansion, for a given substance.

Obviously, we cannot have linear expansion in liquids, so that in this case only the cubical expansion can be dealt with. The coefficients here are greater than those of solids, since liquids expand to a greater extent than solids under similar ranges of temperatures. Here are a few examples of the cubical coefficients for a rise of 1°C. in the temperature: alcohol, 0·00105; glycerine, 0·00052; mercury, 0·000182; water (over 10°C.), 0·00043.

WHY WATER PIPES BURST

Water is an extraordinary exception to the rule that bodies expand when heated and contract when cooled, for water does not contract on cooling below 4°C. but actually expands! It continues to expand regularly until the water freezes, and at this point the expansion becomes even more rapid. At 4°C. water is contracted as far as it will contract by cooling, and this temperature therefore is the temperature of the maximum density of water. As a given mass of ice requires a larger volume than a corresponding mass of water, ice is lighter than water and so it floats on water. It is this expansion of water on freezing that causes burst water pipes during a severe frost. The fracture occurs at the time of freezing but does

not become apparent until a thaw sets in. Then the ice in the pipes melts and allows the water to rush through the fracture.

We have spoken of the increase in the size of orbits of molecules that results from the application of heat to a substance. We should make it clear that because the molecules are so minute the actual movement is extremely small. It is because of the very great number of molecules that the sum of their movement in expanding makes a movement that is perceptible. This movement may be large enough to be detected without measuring instruments. For instance, in long bars of metal the expansion will be apparent even when there is only the comparatively small change in temperature as between a summer day and a frosty day in winter. A 100 ft. bar of aluminium will show an increase of $\frac{4}{5}$ in. between freezing point on winter mornings and the 30°C. of a summer noon. Cast iron is affected to a rather less degree, the difference being $\frac{1}{3}$ in. A 100 ft. glass rod would increase its length by $\frac{1}{4}$ in.

Although only small, these variations are very important, and consequently expansion and contraction have to be allowed for in engineering undertakings. Engineers make allowance for expansion in steam pipes by inserting a curved or U-shaped section. This bends easily and so gives the necessary margin of movement.

For the same reason, railway lines are laid with small spaces, called "expansion joints", between the ends of the rail lengths (Fig. 18), for there may be an expansion of as much as $\frac{1}{4}$ in. in a 60 ft. rail. Over these spaces the carriage wheels "tap, tap", as the train runs. On a cold day, when the rails are contracted and the spaces at their widest, the tapping of the wheels is more noticeable than on a hot summer day when the rails are practically continuous lengths.

On the other hand, tram rails are welded together at the joints to form continuous lengths. These rails are sunk in the roadway and surrounded by concrete and granite blocks, so that they are more protected from the changes in temperature to which the unprotected railway rails are exposed. Similarly, we may notice that telegraph wires tightly stretched from post to post in winter appear to "sag" in summer because the rise in temperature causes them to stretch.

EXPANSION OF BRIDGES

The expansion effect is even more noticeable in large bridges. Allowance has to be made accordingly by mounting the girders on rollers to allow them to expand and contract freely (Fig. 19).

Sometimes the girders are fixed to the shore ends by giant hinges, to give the necessary movement, which if not allowed for would result in the buckling of the bridge. In suspension bridges the differences of temperature are allowed for by carrying the cables over saddles resting on top of massive towers. These saddles move on rollers that allow of easy movement to accommodate the varying lengths of the suspended span.

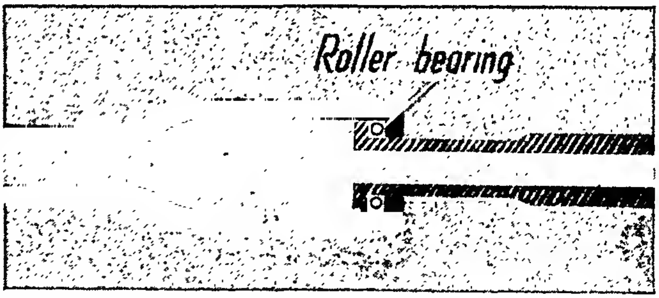


Fig. 19. The sliding joint sometimes used in bridges, to allow for the expansion and contraction of the metal parts.

Fig. 20. How metal tyres are shrunk on to the wheels of locomotives. Notice the two wheels on an axle in the left background ; one has its tyre on, the other has not.

Courtesy L.M.S. Railway.

In the great Brooklyn Suspension Bridge at New York the wires of the cables each consist of nineteen separate strands, and comprise in all nearly 200 miles of wire to form the span of 1,595 ft. It was found essential that each of these wires should be tensioned and secured into place in absolutely uniform weather conditions. The importance of this was realised when it was found that every 1°F. difference in the temperature caused a corresponding deflection of $\frac{1}{8}$ in. in the "sag" of the cables. Consequently, unless the cables had been secured under uniform conditions of temperature, some of them would have been longer than others and the whole of the suspended span would have been thrown out of alignment.

In the case of the Manhattan Suspension Bridge, which has a span of 1,470 ft. ...l is suspended by four cables con...ning 24,000 miles of wire, the saddles do not move on the tops of the towers but are bolted to them. In this case the towers are of steel, whereas those of the Brooklyn Bridge are of masonry to which the saddles could not be so rigidly fixed. Owing to variations in temperature, and to alterations of load, the summits of the towers of the Manhattan bridge may at times be deflected toward the centre of the river by as much as 24 ins.

EXPANSION ON FORTH BRIDGE

There is a difference of as much as 1 ft. in the length of the girders of the Forth Bridge (5,349 ft. 6 ins. in length) on hot and cold days, and this has to be allowed for by using expansion joints. When this bridge was being constructed the girders were carried out from each cantilever arm so that the rivet holes on the joint plates were nearly adjacent to be ready for their final joining-up. The ends were supported on rocking

columns to allow for expansion and contraction. A bright day was chosen for joining the two cantilever girders into one continuous girder, when it was hoped that sunshine would cause a sufficient rise in temperature to expand the metal by the necessary amount to enable the girders to be joined. The girders had been carefully set out and were extraordinarily near alignment both horizontally and vertically in the position they were intended to occupy. When the Sun rose the bridge responded to the warmth, and the two unconnected girders expanded and gradually moved towards each other. Calculations were upset, however, by the springing-up of a cold north-east wind. This caused the expansion of the girders on the eastern side of the bridge to lag behind that of the girders on the western side, with the result that while the bolt holes on the west side came exactly into position those on the east were short by ¾ in.

The men on the eastern side could not get their bolts into place and for a time the position looked serious, for it was realised that unless both sides were bolted up simultaneously great stresses would be caused on the western side resulting in disaster when night came. Then the Engineer-in-Charge had a bright idea, just as the bolts were about to be withdrawn on the western side. He had quantities of shavings and oily waste collected, soaked in paraffin, and placed beneath the eastern girder and set alight. Within a few minutes the girder expanded sufficiently to allow the bolts to be driven home.

The expansion of bodies when heated and their contraction on cooling has many useful applications in science and industry. Expansion is used in fixing the metal tyres to the wheels of railway vehicles. The tyre is made slightly smaller than the rim of the wheel, so that when heated it expands and in this state can be fitted over the cold rim (Fig. 20). When plunged in cold water the tyre contracts and then has a tremendously effective grip on the wheel. Similarly, the castings of large guns are "shrunk" on the inner barrels. For the same reason, the rivets of boiler plates and ship plates are placed in position when hot. They are hammered home in this condition so that when cold they will have a firmer grip by contraction.

BI-METALLIC THERMOMETERS

Then again, expansion is used to measure temperature by means of thermometers. These may be of the mercury or alcohol type to which we have already referred, or of a type that relies on the fact that different metals expand at different rates under the application of a given degree of heat. In these bi-metallic thermometers, strips of iron and aluminium, brass and steel, or other metals are riveted together. As brass expands to a greater extent than steel the bar will bend towards the steel side when heat is applied (Fig. 21).

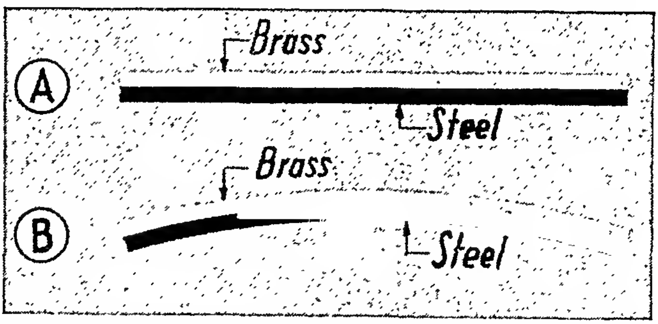


Fig. 21. All solids do not expand at the same rate. Above are compound strips of steel and brass at normal temperature (A). When heated the bar bends towards the steel side (B) because the brass expands to a much greater extent than the steel.

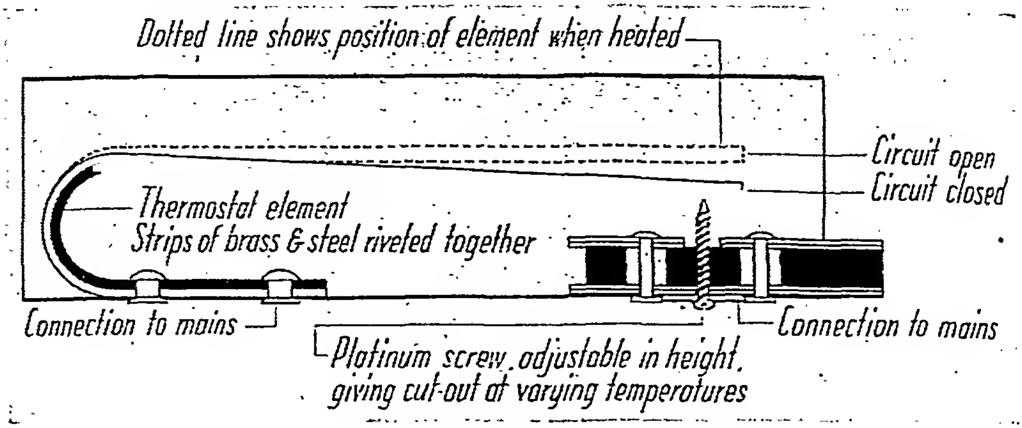
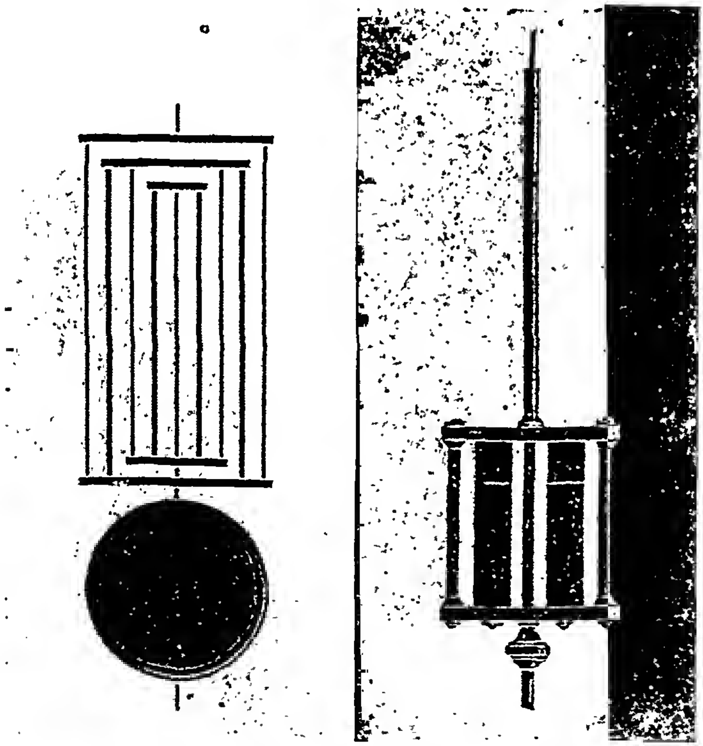


Fig. 22. How the expansion of different metals can be made to control an electric current.

The amount of deflection—varying with the degree of heat—is read off by a pointer on a graduated dial.

The same idea is the basis of the thermostat. In one form, used to control the heat of incubators, strips of steel and aluminium are riveted together. As the strip bends with the heat it moves a lever, deflecting the warm air from the lamp outside the incubator. When the temperature falls the aluminium strip cools and straightens, allowing the lever to admit warm air again; and it is in this way that the temperature is maintained within the required limits.

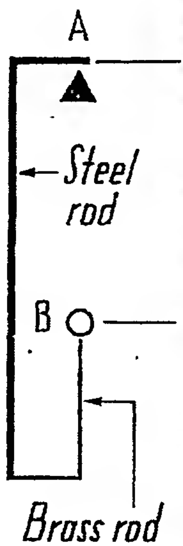
Another and more complex type, of thermostat, consisting of two thin strips of brass and steel riveted together, can be made to control an electrically-maintained temperature within certain prescribed limits. One of the strips is in contact with a platinum-tipped adjusting screw. When a rise in temperature causes the strip to bend up from the position shown in Fig. 22, contact with the platinum tip is broken and the current energising the heating element is cut off. By a different arrangement of contacts the device can be made

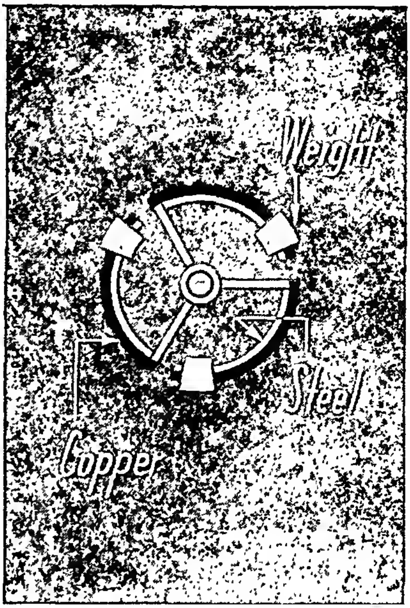


Figs. 23 and 24: Fig. 23 (right) Graham's mercurial pendulum. The two glass cylinders contain mercury compensating for increased temperature. Fig. 24. (left) Harrison's "grid-iron" pendulum. The thinner rods are steel, the others brass. The steel rods expand downwards, the brass rods upwards.

to ring a bell at a predetermined temperature.

Valuable as this expansive property is, it is also desirable to have a neutral substance that is not so affected by heat and cold. A substance of this kind is particularly required for such purposes as the pendulum rods of clocks, and in certain measuring instruments.





Figs. 25 and 26: Fig. 25 (left). The grid-iron pendulum. The brass rod expands upwards so raising the weight and the pendulum is thus kept in a constant position. Fig. 26 (right) watch balance wheel. The positions of the weights ensure correct compensation. The principle is fully explained in the text.

In the earlier days of clock-making very little was known about the properties of metals, and for a long time it was a mystery why a clock should go faster in winter than in summer. Popular opinion was that in some way the Sun affected the clocks in summer. Whilst this idea was correct in the abstract, the difference in a clock's speed was actually due to the expansion or contraction of the metal of which it was constructed. In the hot days of summer the pendulum rod became longer by expansion due to the increased temperature, and so required longer to make its beat. In winter the reverse was the case and the clocks all ran a little fast.

THE MERCURY PENDULUM

It was left to George Graham, an English watchmaker and astronomer, to invent (about 1720) the mercury pendulum. One or two jars of mercury replaced the usual weight on the pendulum. When the temperature increased in summer the mercury expanded upwards, thus counteracting the lengthening of the pendulum rod from the same cause (Fig. 23). With slight improvements, Graham's pendulums are still in use, for they enable a clock to keep very accurate time.

A similar and perhaps better-known device was the "grid-iron" pendulum (Fig. 24) invented in 1726 by John Harrison. This device consists of five rods of steel and four rods of brass, so arranged that the expanding brass rods raise the pendulum by as much as the expanding steel rods lower it. The principle will be clear from Fig. 25 where is shown diagramatically a pendulum hanging from a knife-edge A. The steel rod can only expand downwards so lowering the "bob", whilst the brass rod can only expand upwards, so raising the "bob B". By arranging the downward expansion to equal the upward expansion, the length of the pendulum A-B is kept constant.

A somewhat similar use of the

expansion of dissimilar metals is found in the balance wheels of some watches and chronometers. This method was introduced by Thomas Earnshaw in the latter part of the eighteenth century. The balance wheels of a watch oscillate under the influence of a hair spring, and naturally the number of oscillations varies according to the dimensions of the wheel. A rise in temperature causes an increase in the dimensions and so causes the watch to lose time.

MAKING A BALANCE WHEEL

This is counteracted by making the circumference of the wheel of dissimilar metals (Fig. 26), the outer one being more expansible than the inner. The rim is made in three parts, each supported by a spoke or arm of the wheel. Thus, when the temperature rises the end of the segment of the rim nearest the supporting arm is pushed outwards from the centre by the expansion of the arm. At the same time, the other end turns in towards the centre owing to the greater degree of expansion of the outer strip of metal. Exact compensation is obtained by accurate adjustment of the weights fixed to each segment by screws.

Subsequent researches produced an ideal metal for clock pendulums. This is an alloy of 64 per cent. steel and 36 per cent. nickel, known as "invar steel". Its linear coefficient of expansion is only ·0000009, some thirteen times less than that of either of its constituents. A 39-in. pendulum of invar heated 1°F. expands only about 0·00002 in.

Unlike solids and liquids, all gases have the same rate of cubical expansion unless in contact with a liquid. The French physicist Charles found that a gas expands by $\frac{1}{273}$ of its original volume for every 1°C. increase in temperature, equal to a coefficient of 0·00366. This is known as "Charles' law of temperature".

The reason why gases differ from solids and liquids in the degree of their expansion is that the molecules of a gas are comparatively too far apart from each other for them to be able to attract each other individually. When a gas is heated the movement of the molecules is speeded up. By whatever extent the temperature is raised, there is always a corresponding and similar increase in the energy of the molecules, unimpeded by any mutual attraction of the molecules, so that all gases expand equally.

Heat that enters into the composition of a body in the process of changing its nature—for example, by melting it—loses its character of temperature. In such form *latent heat*, as it is called, produces no change in the temperature that can be registered by a thermometer. An example of this is afforded by applying heat to a mixture of ice and water. No matter how much heat is applied it will be found that the temperature of the mixture remains constant until all the ice has melted. Only then does the mixture show a measurable rise in temperature. Now, what has happened to the heat so applied that fails to record its presence? It is, in fact, contained in the water as latent heat.

ABSORPTION OF HEAT

Thus, when a solid melts, or when a liquid boils, it takes in a certain amount of heat without alteration in the measurable temperature. No change of state is possible without absorbing or giving out heat. It requires 80 calories of heat to melt 1 gramme of ice, and the melted ice (water) will have a temperature of 0°C. Similarly, 540 calories are required to convert one gramme of water into steam, without any change in its temperature. If this gramme of steam could be condensed into water, and the water then frozen into ice, an identical amount of heat would be given out without any change in the temperature.

The reason for all this is that the heat given out by a body when solidifying, or taken in at liquefaction, is employed in carrying out the internal changes of the structure from a liquid to a solid, or vice versa. When ice melts, the applied heat is changed into potential energy, owing to the separation of the molecules during the transformation of the substance from the solid to the liquid form. Because this heat alters the internal arrangement of the molecules without actually causing them to vibrate faster, there is no increase in temperature.

VARIATIONS IN BOILING POINT

We have already seen that the boiling point of substances varies, and that some require a larger quantity of heat to raise them to a given temperature than others. If we mix a pint of water at 50° with a pint at 100°F. we shall have 2 pints, the temperature of which the thermometer will show to be 75°. On the other hand, if we mix a quantity of mercury at 100° with an equal quantity of water at 40°, the temperature of the whole will not be 70°, but 60°, the mercury losing 40° and the water gaining 20°, according to the thermometer. Yet the additional 10° lost by the mercury must be in the water, which we thus see has a greater capacity for storing heat than mercury. To put it in another way, a larger quantity of heat is required to raise water to a given temperature than is required by mercury. It is because mercury has what is called a low *specific heat* that it is used in thermometers, for it comes rapidly to the temperature of its environment. On the other hand water is unsuitable for thermometers because it stores much heat, and is heated and cooled only slowly.

When a solid passes to a liquid state or a liquid to a gas, we have evidence of latent heat, for when these changes take place a large quantity of heat is absorbed, combined, or fixed. Correspondingly, when a gas passes to a liquid, or a liquid to a solid, a quantity of heat is set free. The whole principle of refrigeration is based on these properties, a liquid being made to pass to a gaseous state and so absorb heat from the refrigerating chamber.

An important property of heat is that known as *conduction*, the process by which heat is transferred from one body to another, or from one part to another part of the same body. We have seen that when heat is applied to a body the molecules are "speeded-up" and vibrate in wider orbits. If one end of a poker is heated, the molecules in that part are caused to move more quickly than the molecules in the cool part, and in this speeding up they knock against the adjacent more slowly moving molecules in the cool part. By attraction and repulsion they soon set them moving more strongly, passing on their energy until, if the application of heat is continued, the time comes when these more slowly moving molecules are vibrating as rapidly as the others. This effect goes on gradually throughout the whole length of the poker, until all the molecules have been speeded-up and the whole of the poker is heated. If the poker is removed from the fire, it commences to cool—the movements of the molecules at the handle end slow down, and act as a brake on their neighbours. The effect spreads gradually through the poker, until all are vibrating at their normal rate again, and the poker is at its normal temperature.

CONDUCTION OF HEAT

Exactly as is the case with an electric current, we find that some substances conduct heat better than others. Generally speaking, the densest bodies have the greatest powers of conduction.

Thus, metals are better conductors than stones, hardwoods, and so on. This is one reason why metal is used for making kettles and pans, because it more easily conducts the heat from the gas-ring or the fire to the liquid being boiled. Domestic utensils must be made of good conductors, therefore, but to enable them to be handled, the handle is generally made of wood because it is a non-conductor. Silver has a high conductive value—786 times that of water—and a solid silver spoon placed in a cup of hot tea is too hot to hold with comfort after a few seconds. On the other hand,

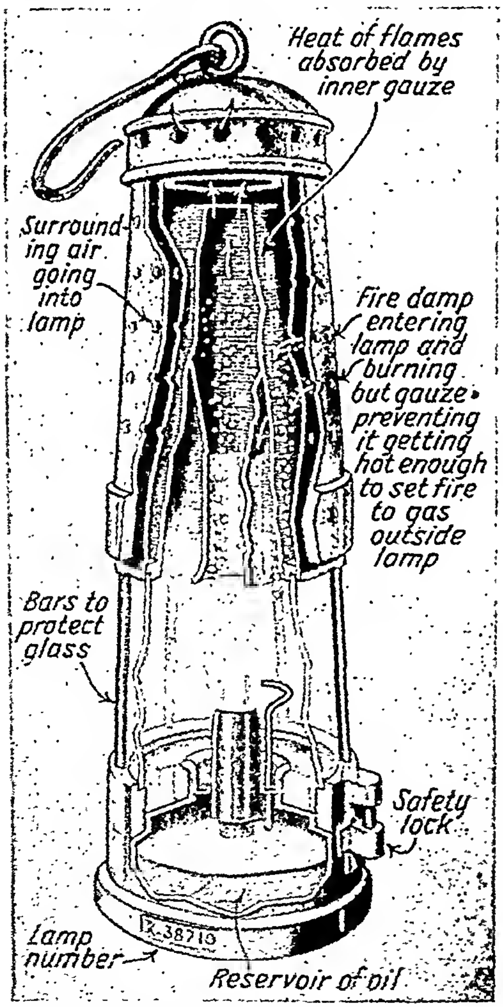


Fig. 27. A sectional view of the modern miner's safety lamp based on that of Sir H. Davy.

a spoon of, say, plated brass—the comparative conductivity of which is 171 times that of water, or about $4\frac{1}{2}$ times less than that of silver—will not so readily conduct the heat and may, therefore, be handled with comfort.

WHY SAUCEPANS ARE METAL

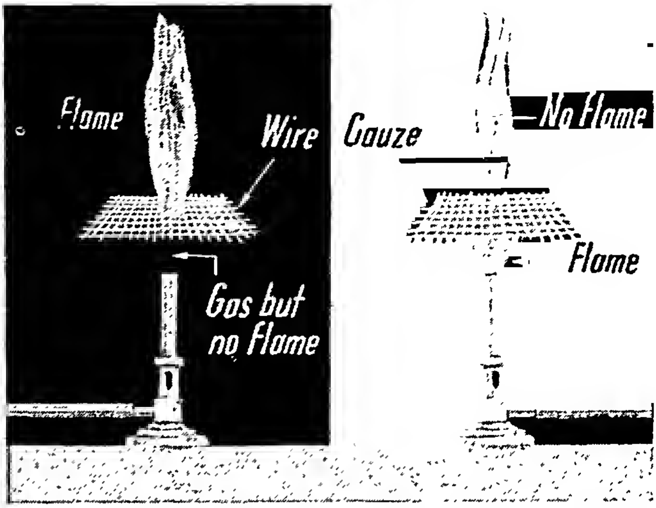
Another reason for the use of metal for domestic purposes is that metal pans do not crack when subjected to a sudden rise in temperature, as glass does. Any change in the shape of a metal pan owing to expansion is of a bending rather than of a fracturing nature. Boiling water poured into a thick tumbler will immediately cause the inside layer of glass to expand, and as the heat has not had time to get through to the outside, the outside layers have no cause to expand and refuse to do so. The molecules are not speeded-up quickly enough to keep pace with the movements of those on the inside layers, and losing their grip on them the glass cracks.

Substances that are good conductors of heat feel cold to the touch, for they conduct the heat of our fingers rapidly from the body. For example, wood does not feel as cold to our touch as iron, and it is not as good a conductor of heat.

As a general rule it is safe to say that good conductors of electricity are good conductors of heat.

Taking the relative conductive value of water as 1, the comparative conductiveness of some other substances are: copper, 743; iron, 143; lead, 57; mercury, 10·7; glass, 1·2; flannel, 0·021.

One of the most important practical applications of the good conductivity of metals is the miner's safety lamp (Fig. 27) invented by Sir Humphry Davy. The principle is based on the fact that if a flame from a gas burner is brought near a piece of wire gauze the flame does not penetrate it (Fig. 29).



Figs. 28 and 29. The Principle of the Safety Lamp. Flame cannot pass through fine wire gauze. Fig. 28. (Left) When gas from a jet is lit above gauze, no flame appears below. Fig. 29. (Right) When gas is lit below gauze, no flame appears above.

This is because the wire is so good a conductor that the heat of the flame is conducted away and the temperature of the unburned inflammable gases above the gauze is left below ignition point, so that they do not ignite above the gauze.

On the other hand, if the gauze is placed over a gas burner and the gas turned on, it may be ignited above the gauze, and the flame will not spread below it (Fig. 28). In the miner's lamp (Fig. 27) the flame is given by oil, and is surrounded by iron-wire gauze of fine mesh. The inflammable gas of the mine passes through the gauze and is consumed inside the lamp; but no flame is able to pass outwards through the gauze to ignite the gases in the mine, and so cause an explosion.

There is no substance that is an absolute non-conductor of heat, although some substances are very poor conductors and therefore may be regarded as insulators. This we may test for ourselves by holding a stick in the fire. We do not experience any sensation of heat, even if our fingers are placed near to the heated extremity. On the other hand, an iron rod will cause a burn even before any part of it becomes red hot.

CLOTHES AND TEMPERATURE

Our clothes are designed with a view to using the property of non-conductivity to the best advantage, the idea being to imprison in the textile fibres a layer of air with which to surround out bodies to serve as a non-conductive layer. Wool is a bad conductor of heat, for its fibres include innumerable spaces that are filled with air—also a bad conductor—and for this reason we use it for our winter clothing instead of cotton, which is not so effective as an insulator.

Taking the relative non-conductive value of felt as 1, the comparative non-conductiveness of some other substances are: loose wool, 3·35; feathers, 1·10; loose straw, 0·75; cork, 0·71; sawdust, 0·68; wood and asbestos, 0·50; sand, 0·17; and stone, 0·02.

Liquids and gases conduct heat badly, although they acquire it readily. We can prove this in the case of a liquid by filling a glass tube with water and heating the upper part in a flame. Despite the fact that the water at the surface boils, we can hold the tube by the lower end without burning our hand. Ice placed at the bottom of the tube will remain unmelted for some time, even though the water at the top boils (Fig. 30). It is true that although the water cannot conduct the heat downwards, the lower levels do ultimately become heated, but this is due to the heat being conveyed

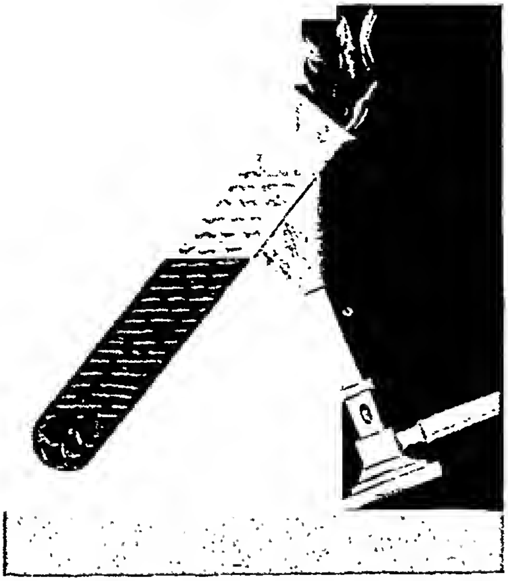


Fig. 30. Water is a bad conductor of heat. Pieces of ice jammed at the bottom of a test-tube will not melt even though water at the top of the test-tube is boiling.

down the sides of the test-tube itself.

That a gas is also an imperfect conductor may be illustrated by pouring liquid air on to the hand. The temperature of liquid air is about $-180°C.$, compared with which a piece of ice would be like a red hot coal. This intensely cold liquid when poured on the hand does no harm, for the warmth of the hand immediately causes the liquid in contact with it to evaporate, the gas so given off forming a non-conducting layer between the hand and the liquid.

BAD CONDUCTORS OF HEAT

Bad conductors have their uses, for although we require good conductors for "pots and pans" there are times when we want to make use of bad conductors. When we wish to keep things hot or cold, jars made of china or stone are more efficient than metal jars, but even so they pass a good deal of heat. We have seen that gases conduct very little heat. If we could surround a hot obj with a layer of gas we should have very efficient non-conductor. As cannot very well do this the next b thing is to wrap the object in a blank or in cotton wool. These materi contain many spaces between th

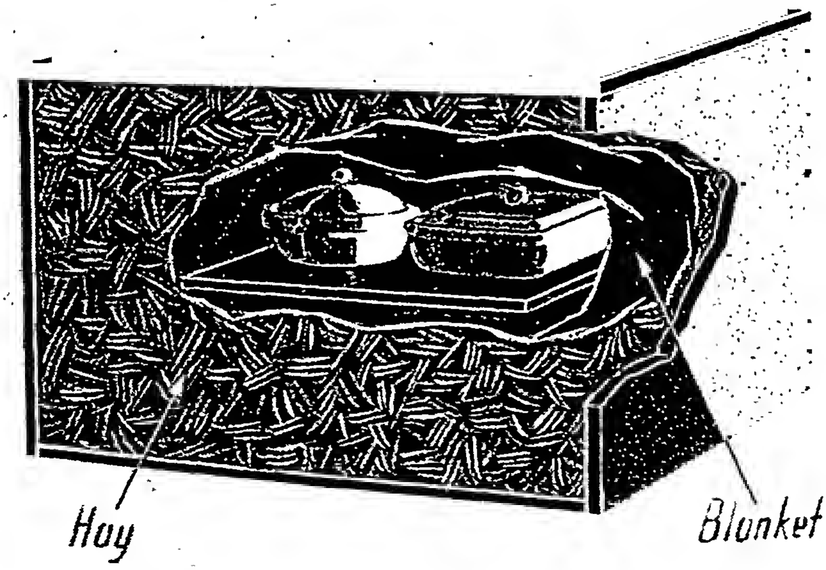


Fig. 31. A box packed with hay conducts heat badly, and in it food may be kept hot for hc

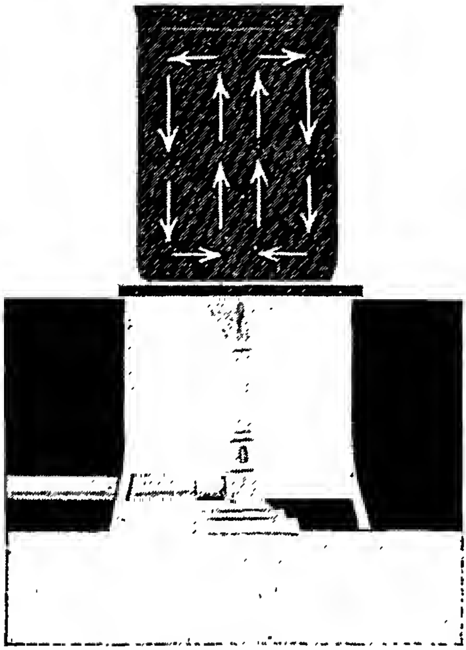


Fig. 32. Convection currents in liquid. Warm water ascends up the centre of the pot and descends by the sides. Thus the heat is distributed throughout the whole of the liquid.

fibres, and as these spaces are filled with a gas—air—they form a very efficient insulator against heat or cold. The "hay-box" is another example of this (Fig. 31). A hot meal is placed in a nest of hay, and covered with a cloth and more hay above, the whole being put into a box. The heat escapes so slowly that the meal will remain hot for hours. Hay-boxes are often used by shooting parties to keep their lunches hot until they are ready for them.

Exactly as a blanket or a hay-box will keep the heat in, so will they keep heat out. Ice wrapped in a blanket will not so easily melt, for the blanket prevents the heat of the outside air penetrating to the ice. Slag-wool, asbestos, and cork are also good insulators, and keep heat in or out as may be required. They are used for lining refrigerators, cold stores, and so on. A vacuum flask, with its double walled space emptied of air, is an ideal means of keeping things hot or cold, since a vacuum is not a conductor at all. The heat can only escape by radiation, which is cut down by silvering the glass walls to reflect the heat back, by means of the glass at the neck of the flask.

WHAT IS CONVECTION

Another method by which heat may be transferred from one body to another is by *convection*, or the bodily movements of liquids and gases caused by the differences of temperature between different parts of the same substance. We have seen that liquids and gases do not readily transmit heat, but both readily acquire it by this process of circulation called convection. When heat is applied to a liquid from below, the lower layers are warmed first, and as the heated parts of the liquid expand they become lighter than the cooler parts and rise to the surface (Fig. 32). Similarly, as the cooler parts are heavier they sink to the bottom and so come into contact with the source of heat. They in turn

Fig. 33. An electric Immersion Heater, fitted near the bottom of a water tank.

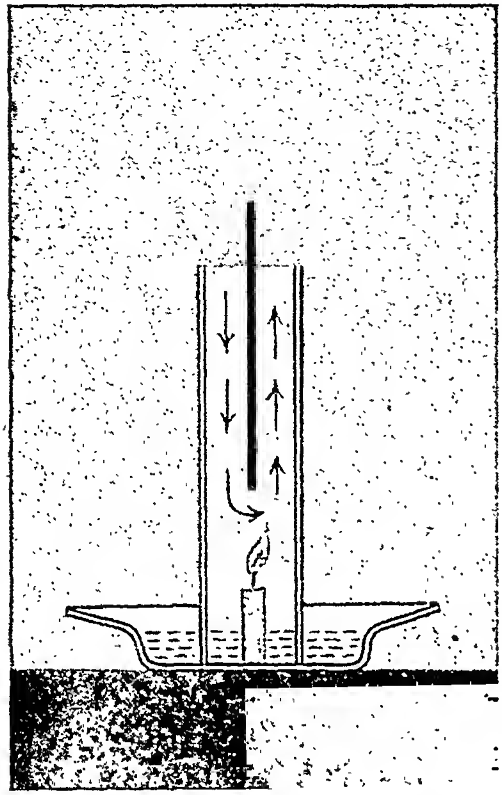


Fig. 34. Convection currents in a gas. A cardboard division in a candle-funnel will make a down draught to left and an up draught to right. A similar movement occurs in a room.

are heated, expand and rise, and the less heated parts from the top sink. Thus circulation, or convection, is set up by which the applied heat is distributed throughout the whole of the liquid.

It is for this reason that a fire is placed *under* a boiler. If it were placed at the top, the water would only become heated immediately underneath the fire (compare Fig. 30) and as hot water cannot sink in a boiler of cold water, the lower layers could not become heated. It is for this reason, too, that in a hot water cylinder fitted with an immersion heater the heater is placed at the bottom of the cylinder (Fig. 33). When the heater is working, the heated water will not be found in contact with the heater itself but at the top of the cylinder, having risen and allowed the cold water to come into contact with the heater. So the process will continue as long as the heater is working, the water circulating until the cylinder of water is heated.

PRINCIPLES OF VENTILATION

Our systems of ventilation are based on the establishing of convection currents between the outside air and the air in the room to be ventilated. The principles applied in ventilation are illustrated in Fig. 34. If a lamp chimney be placed over a lighted candle standing in water (in order to make the base of the chimney air-tight) the candle will go out. This is due to lack of ventilation, for no air can flow down the chimney. If a piece of cardboard is inserted as shown in the drawing,

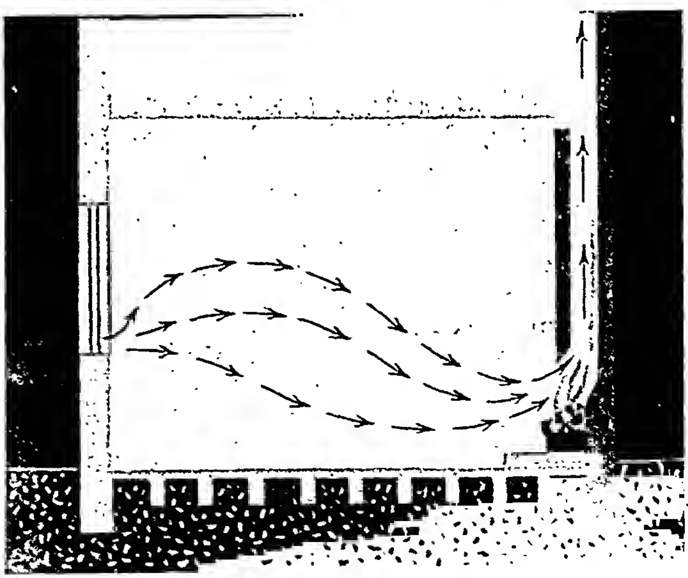
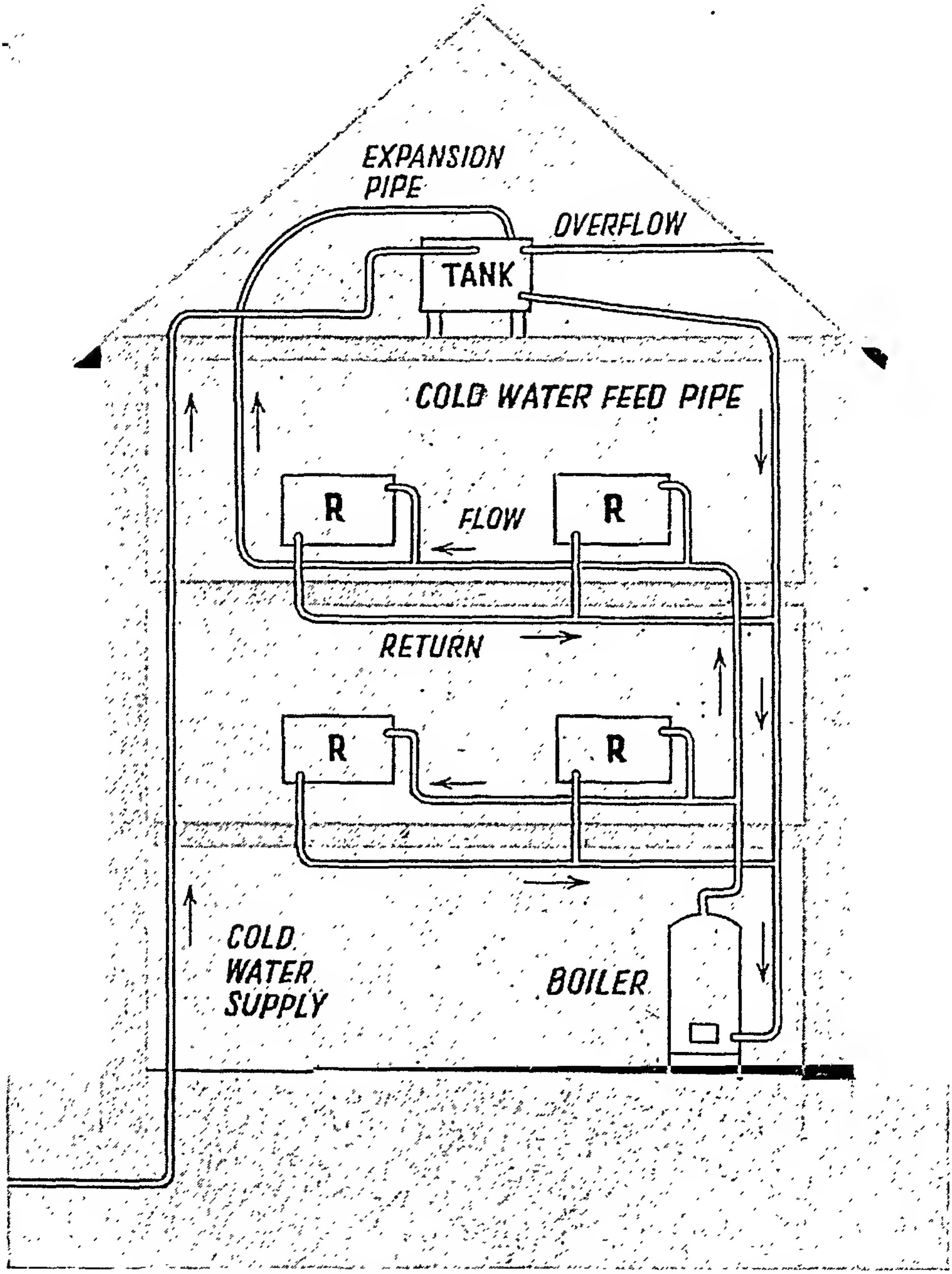


Fig. 35. Why smoke goes up the chimney. The heated air from the room rises and is replaced by cooler air from the window.



CONVECTION AS THE PRINCIPLE OF CENTRAL HEATING.

Fig. 36. In the hot-water system of central heating—that most commonly used in Great Britain—the hot water rises from the boiler by convection to circulate through pipes and radiators (marked R in this diagram) and then, having lost the greater part of its heat, is returned to the lowest point of the boiler. There it is once more heated and leaves by the pipe at the top of the boiler, to begin another circuit of the building.

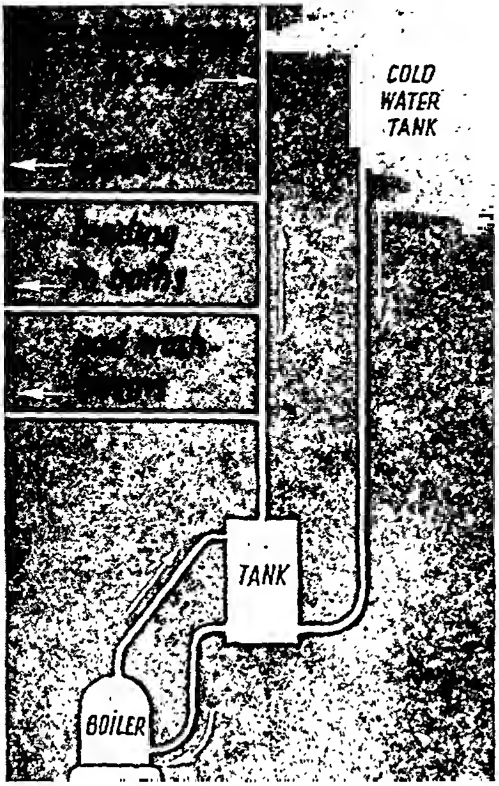


Fig. 37. How convection currents regulate the domestic hot water supply. Hot water goes from boiler to tank to be spread through the house.

however, the candle continues to burn. It does so because there is an up-draught at one side and a down-draught at the other, since the hot air rises up one side and cool air comes down the other side to replace it. If a cigarette is held near the cardboard division, it will show by its smoke the direction of the air currents.

A similar movement takes place in a room, when the heated air from the fire ascends up the chimney and is replaced by cool air from the window (Fig. 35)

Convection, in which heat is borne by moving masses of steam, is the principle of one form of steam-heating apparatus. Either waste steam or steam specially manufactured for the purpose is carried in pipes through the building to be heated. The heat radiates from the large surfaces of the radiators in the various rooms. As it performs its work and gives up its heat, the steam condenses and returns to the boiler by its own gravity. Similarly, in the hot water system of heating, the hot water rises by convection, circulating through pipes and radiators and returns cold to the bottom of the boiler (Fig. 36). Domestic systems of hot water supply to baths and washbasins work on the same principle (Fig. 37).

Heat is also transmitted from one body to another by *radiation*, but here bodies are not in contact, but entirely separated. The Sun's heat reaches us by radiation, as does the heat from a fire or electric radiator. Radiation is made possible by means of the ether, and this medium we shall consider more fully in a subsequent chapter. Radiant heat is caused by the rapid vibration of the molecules in the body giving out the heat. These vibrations set up vibrations in the ether, causing waves that are propagated in all directions. When these waves fall on another body they tend to cause the molecules in that body to vibrate violently, and so produce a rise in temperature.

CHAPTER 13

SOUND

Sound—or, more precisely, a sound wave—may be described as a vibrating movement caused by the setting in rapid motion of the particles of an elastic body. Sound itself does not exist in the outer world, for it is only something that makes itself felt within the brain when the vibrations strike the ear-drum and stimulate certain nerves.

Sounds are produced by anything that will cause vibrations rapid enough to make the air to vibrate, such as knocking on a door; the firing of a gun; the scraping of a string with a bow, or the plucking of it. The vibrations of a tuning fork produce melodious sounds as do those of a column of air in an organ-pipe. Some things vibrate too slowly to produce sounds—as, for instance, our legs when walking, a windmill, or spokes of a bicycle wheel.

It is not difficult actually to see the vibrations of many bodies when producing sounds—particularly the strings of musical instruments, large bells, membranes of drums. If suspended pith-balls are brought near to a bell just after it has been struck, or near a wine glass that is stroked by a violin bow, the balls will at once commence to oscillate, thus giving evidence of the vibration of the air in the vicinity (Fig. 1).

Sound vibrations may be rendered visible in several ways. One of the earliest experiments in this direction was demonstrated in 1862 at the London Exhibition by Rudolph Koenig. He showed how a flame can be made to rise and fall in sympathy with sounds, and by means of a series of rotating mirrors he was able to make drawings of the characteristic outlines of various sounds (Fig. 2). A little later, although the science of photography was in its infancy and its applications were very limited, it was found just possible to photograph Koenig's flames, and the results were regarded as a great achievement. In 1897, by using an acetylene flame instead of gas, better-defined photographs were obtained. Of course, in more recent years progress in research has been very rapid so that Koenig's

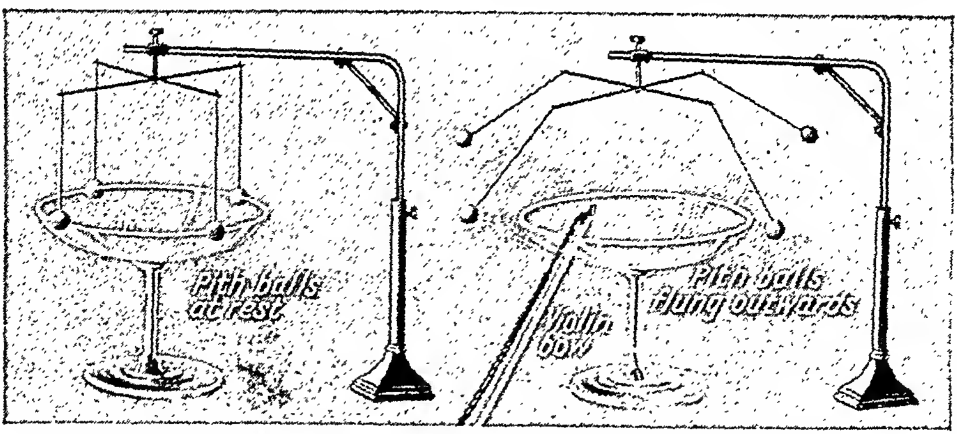


Fig. 1. When pith-balls are suspended near the edge of a wine glass that is stroked with a violin bow, they will fly outwards, thus proving air vibration.

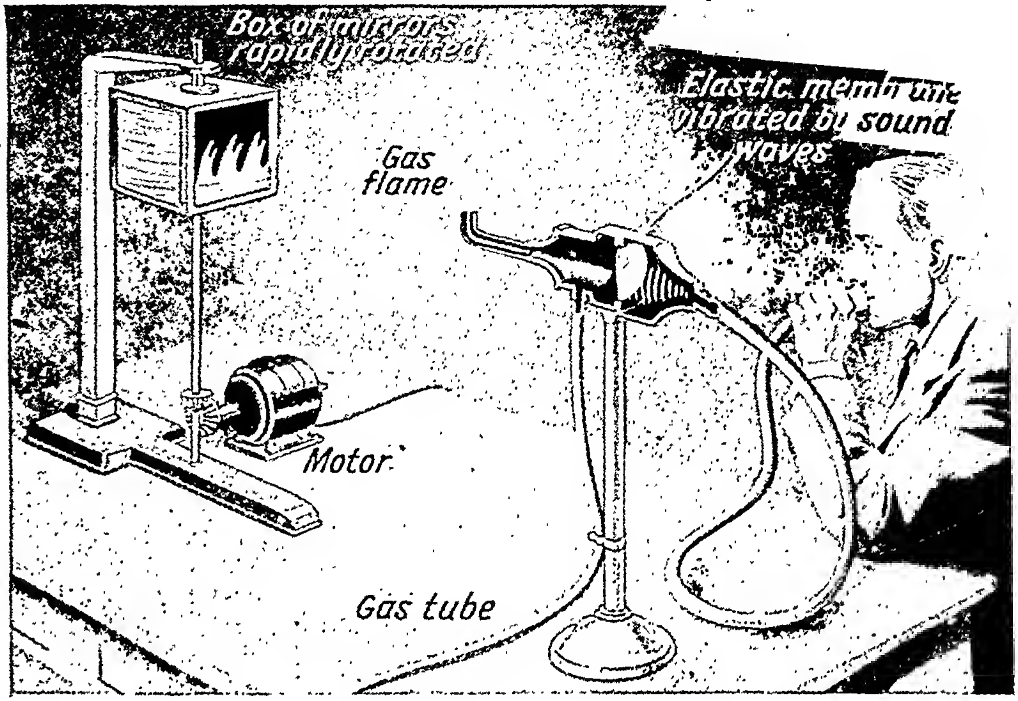


Fig. 2. An early experiment to make sound waves visible. Sound vibrations impinging upon a membrane will distort a gas flame. Variation in the flame may be observed in rotating mirrors. This experiment was demonstrated by Rudolph Koenig at the London Exhibition of 1862.

experiments, although still of laboratory interest, are now regarded as somewhat crude; yet at the time they were considered one of the marvels of science.

Another experiment by which sound vibrations can be rendered visible is to sprinkle a vibrating body with fine sand or powder. In this way, sonorous vibrations may be shown by using a violin bow on the edge of a sheet of glass, held by a small wooden vice or placed on a stand. The glass is sprinkled over lightly with lycopodium powder—a very fine powder obtained from the spore-cases of certain plants. The glass plate emits sounds that vary in accordance with the vibrations. By applying the bow and touching the glass plate at various points along the edges, a wide variety of beautiful figures can be produced (Fig. 3), for powder collects along the "nodal lines" where there is no motion at all of the glass.

A similar symmetrical arrangement will be seen if sand is sprinkled over a membrane stretched over the mouth of a funnel. A cord, passed through the membrane and held there by a knot, is drawn through the fingers (previously smeared with resin), thus causing the membrane to vibrate. Similarly a thin membrane or piece of tracing paper, stretched over a circular wooden frame and sprinkled over with sand will show the vibrations of a tuning fork or bell held near to it.

When the motion of a sound-wave is sufficiently rapid to strike the ear—that is to say when the regular vibrations amount to about 40 a second—we hear a more or less pleasing sound or a musical note. On the other hand, a single blow, or an irregular motion of air particles, results in a "noise" as distinct from a harmonious sound.

Music has been described as "a noise

that is less objectionable than other noises": an epigrammatic definition that yet states a basic fact. All "noises" and sounds are radiated from their source and transmitted to the ear in an exactly similar manner. The clatter of a tram or a train going over railway points; the noble tones of an organ; the majestic tone of brass instruments; and the singing tones of wood, wind, and stringed instruments in a symphony orchestra—all are made audible by exactly the same means. The difference between a musical note and a noise is that the waves from the former are regular and of uniform length, whereas from the latter they are a more or less confused mixture of varying lengths. They form an irregular succession of shocks, as it were, that cause a "jarring" rather than a "soothing" effect to be communicated by our auditory nerves.

There are several methods of generating musical sounds. For instance, if we take a length of piping, open at both ends, and strike one end with the palm of the hand (Fig. 4) we produce a hollow and musical "plop". If the end is repeatedly struck in this manner and the speed of striking gradually increased, the "plops" increase in number. If the striking takes place a great many times a second, the "plops" merge into each other and give the effect of a continuous note. The sound is caused by the hand forcing air into the end of the pipe and slightly compressing the air at that end. As air is an elastic substance this wave of compression passes along the tube and emerges from the other end where—as it is no longer restricted by the tube—it spreads through

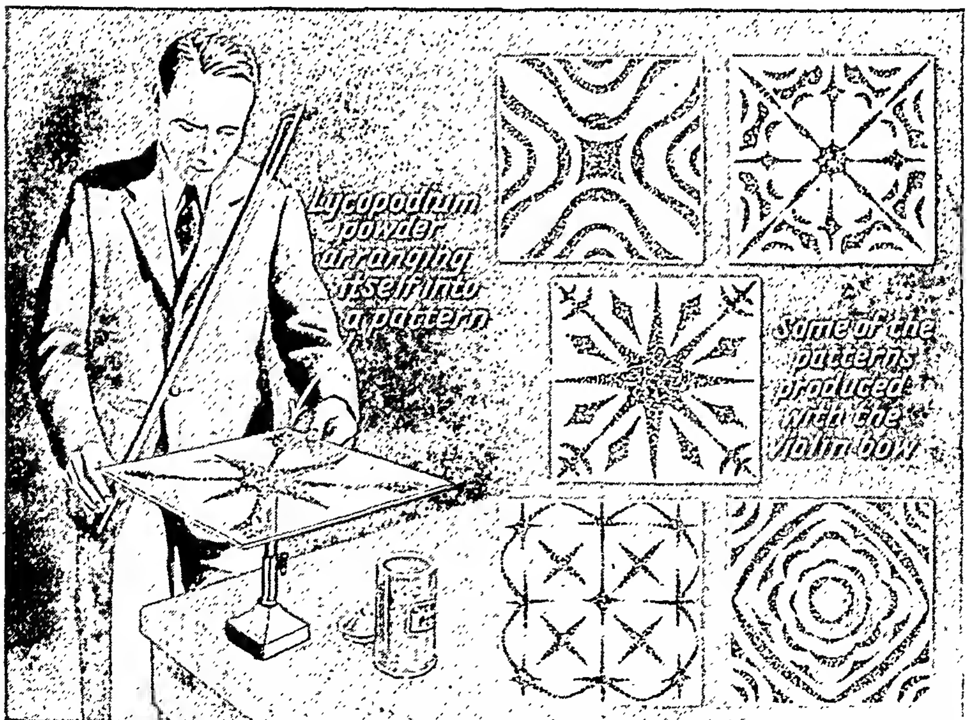


Fig. 3. When a glass plate is stroked by a violin bow, its emits vibrations. These may be rendered visible by sprinkling the plate with fine powder. Different patterns are produced by varying the strokes and by gripping the plate between thumb and finger in different places.

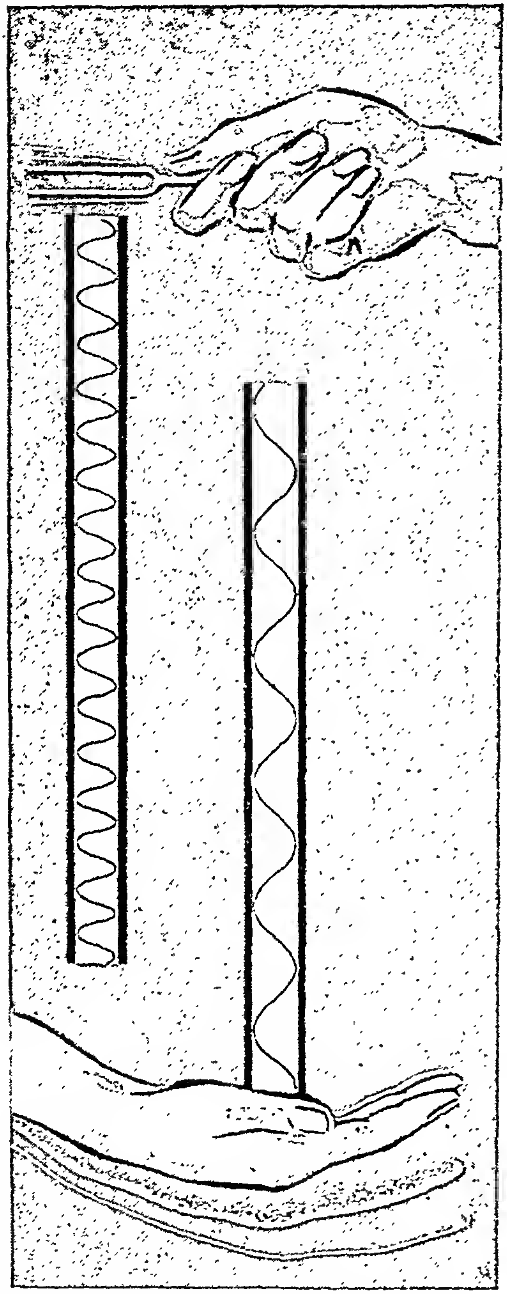


Fig. 4. (Top) A tuning fork will give rise to a series of vibrations producing a musical note in a pipe. Similarly (bottom), if the end of an open pipe is struck a series of vibrations is set up within the pipe.

the air in the form of waves of compression.

Similarly, if we provide some means of agitating, or beating, the air very rapidly at the end of the pipe—as with a tuning fork—a note of a certain pitch is obtained (Fig. 4). If the impulses or waves are increased in their number per second, the sound will rise in pitch—that is to say the note rises in proportion to the increase in beats. Whether a note be high or low is determined by the rapidity of the beats or air waves. For simplicity, these air waves may be termed "vibrations", as in all forms of musical sound production some mechanical vibration is used.

BASIS OF THE PIPE ORGAN

The principle we have discussed is the basis of the organ, which consists of a number of pipes. Through these wind from a compressed air box is passed by opening a pallet. The air rushes through and over a lip, by striking which it sets up vibrations in the pipe (Fig. 5). Different sizes of pipes, and different materials, give different notes and different effects.

Other ways of producing musical notes are by vibrating a string by striking it with a hammer as in a piano; "plucking" a string, as with a harp; vibrating a reed by blowing past it, as with such wood wind instruments as the clarinette or oboe; or by vibrating an air column in a tube or pipe, as with brass instruments (trumpets, trombones, etc.), or with the organ.

If an elastic band is stretched between the hands and someone plucks it, a dull, low note will be heard. It has very little power, however, since the waves set up, although rapid, are small. To increase the "pitch" of the note—but not its volume—it is only necessary to stretch the band tighter between the hands. This has the effect of increasing the number of vibrations per second that the band makes when it is plucked.

To increase the volume of the note, the band can be stretched on a frame as

a string is stretched in the case of a harp, or on a hollow body as in the violin or cello. In these instruments the strings are usually of gut, silk or wire, or a combination of gut and wire. In the case of the violin and similar instruments the strings are stretched over a wooden bridge placed on the hollow body of the instrument, which is reinforced by a sound post to take the pressure from the stretched strings (Fig. 6). When the string is vibrated, the vibrations are transmitted through the bridge to the surface of the hollow body, and this also is caused to vibrate. It sets up sound waves in its interior and these pass to the outside air through the "f-" or sound-holes that are to be seen in the top face of the instrument. Without these sound-holes a musical note would be obtained—due to the vibrating body transmitting vibrations direct to the outer air—but the tone would be dull and without resonance or carrying power. The same principle applies to the harp, although in its case there is no bridge. Instead, the vibration of the plucked strings is transmitted to the frame of the instrument, the lower portion of which is of hollow construction to give the necessary tone.

TENSION IN VIOLIN STRINGS

In stringed instruments the strings are set at different tensions in order to give the required variations in the number of vibrations per second. In the case of some stringed instruments the vibration of the string can readily be seen by drawing the bow heavily across the "open" strings—that is without the fingers pressing on them as when playing. It will be noticed in such a case that the vibration is so rapid as to cause the string to appear blurred.

The vibration necessary to cover a wide range of pitch is very rapid. Middle C on a piano tuned to "German Pitch"

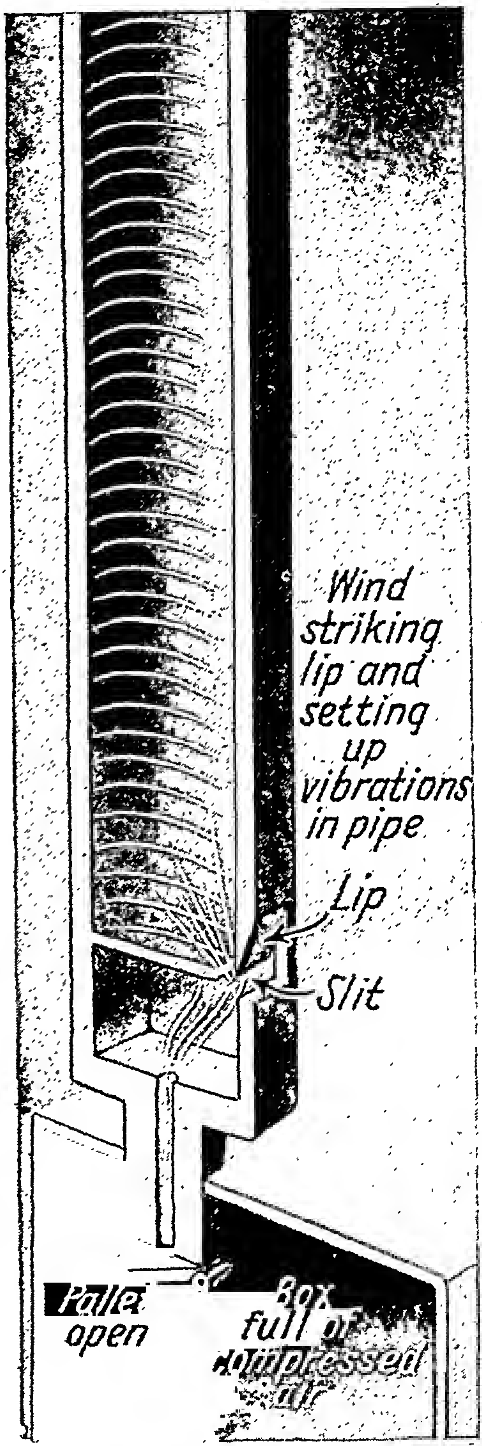


Fig. 5. How an organ pipe produces a note.

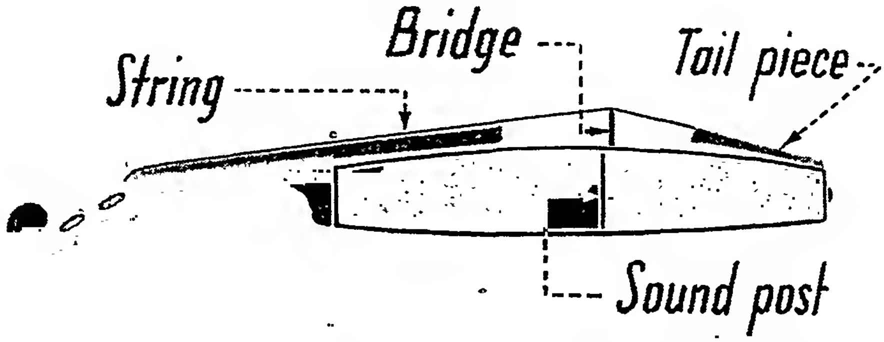


Fig. 6. In a violin the strings are stretched over a wooden bridge on the hollow body of the instrument, which is reinforced by a sound post to take the pressure from the stretched strings.

gives vibrations of 264 per second, but a satisfactory musical note would be heard on an instrument such as the organ when the sound vibrations were only about 40 per second. This is not the lowest possible note, however, as an organ in Sydney, New South Wales, is constructed with pipes 64 ft. in length that give $8\frac{1}{4}$ vibrations per second. The normal lowest note is given by an organ pipe 32 ft. in length giving $16\frac{1}{2}$ a second. At the other end of the scale is the shrillest note in an orchestra—the highest note of the piccolo producing vibrations at the rate of 4,752 per second. The lowest note of some of our greatest bass singers gives a vibration of approximately 50 per second, while the highest note of the famous soprano singers gives about 1,500 per second.

Brass instruments, which is the term applied to the wind instruments of an

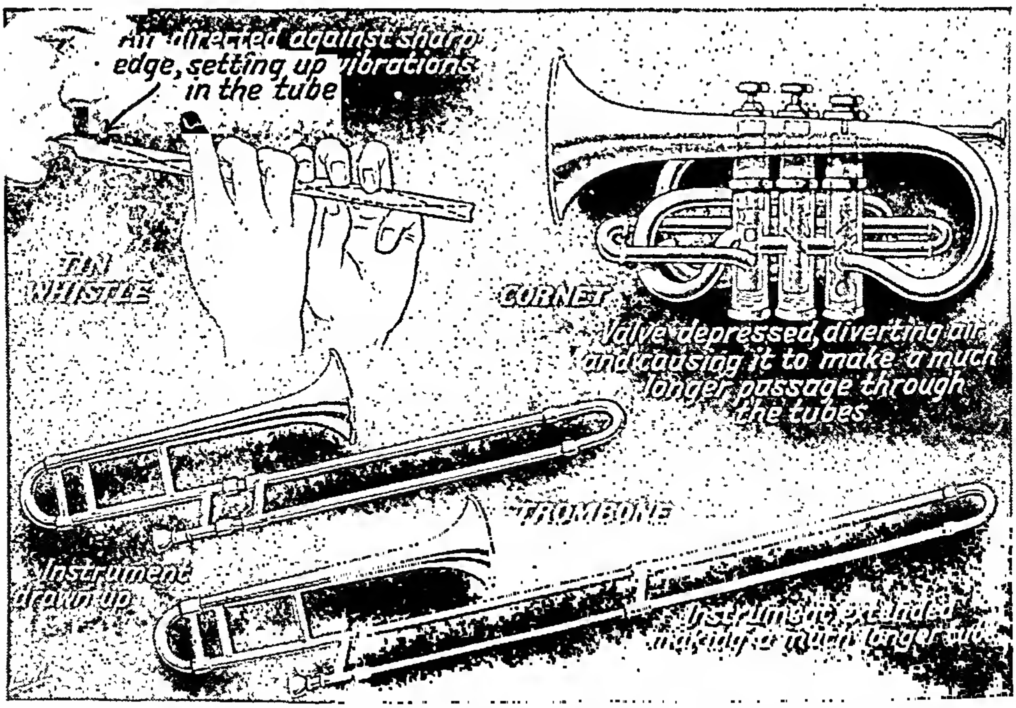


Fig. 7. How different notes are obtained from the cornet and trombone, basically pieces of metal tubing. The effective length of the tubing is varied as required, thus producing different notes.

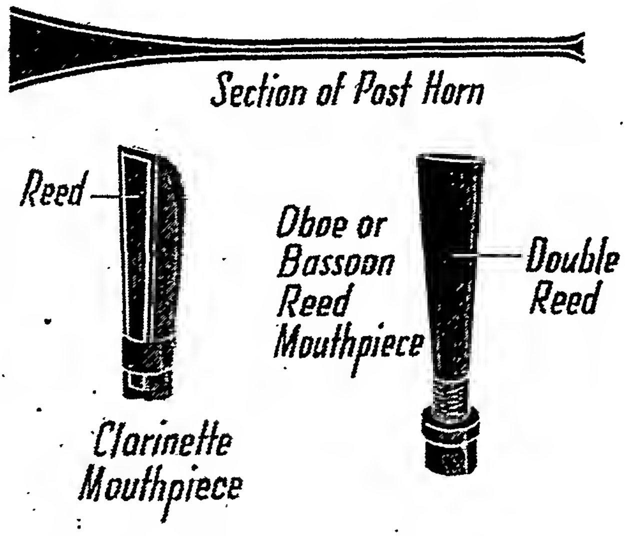


Fig. 8. (Top) The old-fashioned post-horn is virtually a length of piping, the various notes being obtained by different adjustments of the player's lips. (Bottom) The notes of the clarinette and oboe are obtained by vibrating reeds.

orchestra not provided with reeds, are simply lengths of metal tubing of varying diameters. Sound waves are set up by the instrumentalist forcing air through his lips at a certain velocity into a small hole in the mouthpiece (Fig. 7). For convenience in handling and playing, the tubing is coiled into various shapes, but the effect and principle is the same as if the instrument were made of a straight length of tubing. The simplest form of brass instrument is the old-fashioned post-horn (Fig. 8), in which a series of notes is obtained merely by altering the velocity of air through the player's lips. The military bugle and trumpet are very similar, but here the tubing is coiled for convenience.

It will be noticed that with these instruments only a limited number of notes can be obtained, the range being determined by the length of the tube. If other notes are required some artificial means of altering the tube length must be employed. The simplest way of doing this is that used in the slide trombone (Fig. 7). In this the player continues to blow with a velocity that normally would only produce a certain note, but by moving the slide—thus lengthening or shortening the length of tubing—other notes may be obtained.

With other types of brass instruments—as in the cornet—a similar effect is obtained by operating valves that guide the air through small additional lengths of tubing. In yet other cases they shut off portions of the coils either to lengthen or shorten the effective length of tubing used (Fig. 7).

The term "wood wind" is applied to those instruments in which a reed is used to produce vibrations. A reed is a thin strip of cane or metal vibrated by a current of air (Figs. 8 and 9). In the clarinette and similar instruments the reed is in the form of a flat piece of cane that vibrates against an ebonite mouthpiece (Fig. 8). The effect is alternately to cut off and release with great rapidity the flow of air passed through the instrument by the player. By covering and uncovering various combinations of holes in these instruments the effect of a varying length of tubing is obtained, giving a wide range of notes.

USE OF THE DOUBLE REED

With instruments such as the oboe and bassoon, a double reed is used (Fig. 8). The reeds vibrate together to give the same effect on the air column, the note being weaker but of sweeter tone.

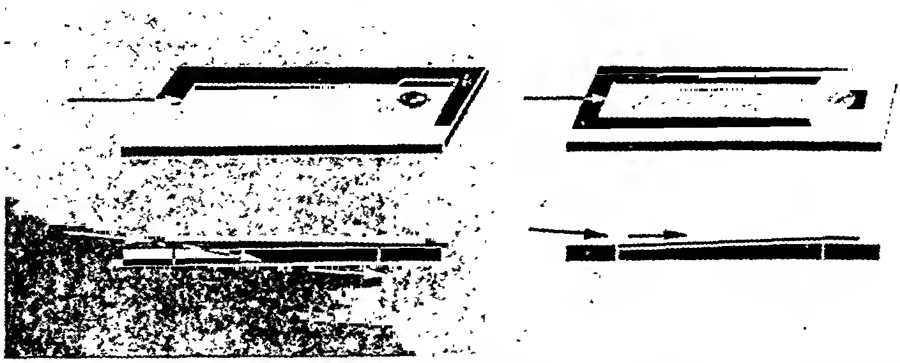


Fig. 9. How a reed is made to vibrate. The air current passes first under the reed (left) and then over it (right). In this way it is caused to vibrate very rapidly and thus to set up a musical note. In the clarinette and similar instruments the reed is in the form of a flat piece of cane.

The flute, which is also classed as a wood-wind instrument, is similar in operation but here no reed is used: the player's lips form the reed in conjunction with the edge of the hole over which the air is forced.

All instruments that are operated by striking with a hammer or stick are termed "percussion" instruments. The piano and similar instruments are exceptions to this rule, being classed with the strings. The comparatively unmusical note given out by the drums, cymbals, etc., is due to the complex vibrations given off, causing a certain distortion of the sound waves. The tympanum, which is a form of drum constructed on a large copper bowl, is capable of being tuned to a definite note, however, and large orchestras use several of various sizes. Tuning is done by tightening or loosening the skin to raise or lower the pitch, so as to harmonise with the other instruments.

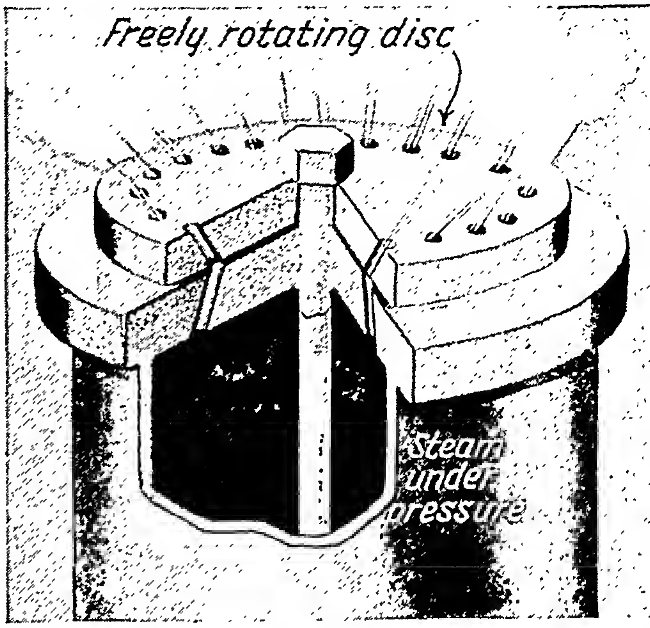
No matter by what means these vibrations may be caused, the sensation we call "hearing a sound" is due to vibrations in the air falling on the eardrum, or "tympanum". From the drum the vibrations are conveyed to the auricular nerves in the interior parts of the ear by a wonderfully delicate series of linked bones known as the hammer, anvil, and stirrup. In reproducing sounds mechanically an artificial imitation of this mechanism of the human ear is used—the diaphragm of the telephone receiver, for instance, corresponds to the tympanum.

WHAT IS SOUND?

Without ears to hear there would be no sound, for all Nature is silent, just as, without eyes to see, all Nature is in darkness. Sound is thus a silent wave motion that is interpreted into a sensation in the brain of the hearing subject. Exactly which part of the ear is the true organ of hearing is as yet a mystery, there being three current theories to account for the transmission of sound to the auditory nerve.

Sound waves spreading outwards from the source producing them differ in one important way from the wave produced by throwing a stone into a pond. In the latter case the wave travels in the water only, and more especially along its surface, and therefore may be said to be a transverse wave on a plane surface. On the other hand, sound waves have a longitudinal direction of vibration—that is to say, the direction of vibration of the air particles is along the direction of travel of the wave. The progression of sound waves differs considerably from the sinuous lines that would depict the movement of a wave in water. Their

movement must be regarded rather as a series of rapid pulsations of particles of air taking place in the direction in which the sound is propagated. Their resemblance to waves on water is only that they present periodical phases in uniform succession.



A siren consists of 2 discs, each perforated with a number of tiny holes, the top one being free to revolve ; the holes are angular so that steam under pressure rotates the disc, alternately shutting off and releasing the steam. This sets up powerful vibrations.

An appropriate illustration of the transmission of a sound wave may be obtained by imagining a number of balls hanging from separate strings, the ball at the end hanging near to a bell as shown in Fig. 10. If the ball at the other end is drawn back and released so that it hits the second ball, the ball nearest the bell will suddenly strike the bell, causing it to ring. The balls in the row, which are all touching do not appear to have been moved, but actually each one has been knocked forward and rebounded by the impact from the first ball. Actual motion has been stopped in the individual balls by the one in front of each, but as the last ball hangs freely, the impulse of the others is translated into motion and the bell rings.

It is in a way similar to this that the molecules of the air transmit series of compressions and rarefactions so that the impulse advances as a sound wave. When a force strikes the particles of the air, these particles are moved to and fro like a pendulum. The particles that are given the original impetus strike their neighbours, and they in turn pass on the vibrations to the next particles and so on, so that a wave of sound is created and travels on until the movement dies out.

It is important for us clearly to understand that this advancing of the sound wave is a wave motion only in

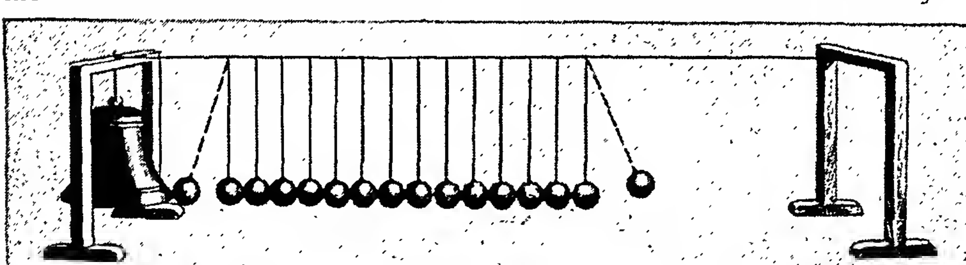


Fig. 10. Illustrating how a sound wave is propagated by vibration.

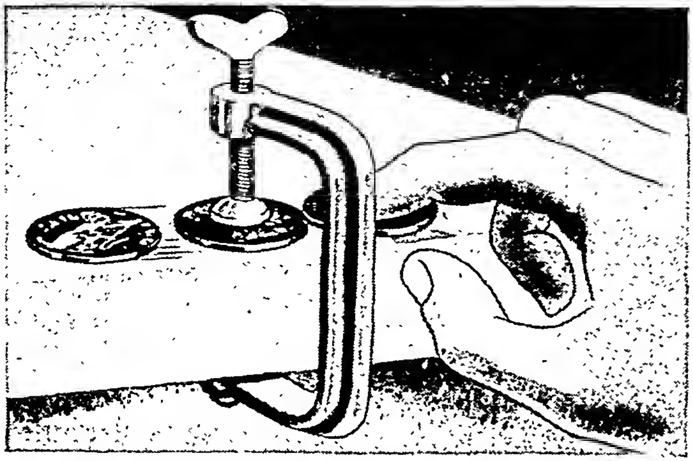


Fig. 11. An experiment with three pennies (see text).

the particles that compose it—*the particles themselves do not move forward.* This may be illustrated by throwing a stone into a pond when a series of concentric waves will be seen to move from the spot where the stone entered the water. If a cork is thrown into the water in the path of these waves it will be seen to rise and fall, but it is not carried along by the waves. This is because the waves are due to the oscillation of the individual particles of water, the movement being communicated to each particle in turn, as in the case of the hanging balls. Similarly, a sound wave is an impulse that travels through the air; it is not the translation of a body of air from one place to another.

A striking little experiment will illustrate more clearly that a sound wave is a form of energy and not an actual movement of particles. Place two pennies on the table, so that they are exactly touching. Hold down one firmly and lightly tap it with a third. The first penny will then be shot forward an appreciable distance, although the centre penny has not moved a fraction of an inch. The energy imparted by the blow has been transmitted through the stationary penny, as in the experiment with the balls and the bell (Fig. 10). Some people, seeing this experiment, cannot believe their eyes and insist that there is a trick and that the centre penny has been moved, but it may be fastened to the table with a clamp if necessary to convince unbelievers (Fig. 11). Even the artist who drew this picture could not accept the experiment, so he screwed a hinge to the table and still the experiment worked—in fact, it worked better than ever!

NATURE OF SOUND WAVES

Some people think that it is curious that all kinds of sounds—such as shrill whistles and deep bass notes—should travel at the same speed, but such is the fact. If two or more tuning forks are vibrated at the same time, the vibrations from each are transmitted independently and simultaneously, as if those from the other did not exist. They resemble the two sets of waves that travel over the surface of a pond, if two stones are thrown into it at the same instant.

It is a fortunate arrangement that two, or more, sound waves pass each other without interference, for, as a result, it is possible to transmit any number of sounds simultaneously without confusion. Otherwise, when listening to an orchestra at a distance we should be able to hear the general musical effect only when quite close to it, for sounds from the shrill piccolo and the drum would arrive at different instants; as it is, we know they all arrive perfectly in time and combine to give harmony. The reason for this is that

the velocity of propagation of all these waves is the same, whatever may be their frequency, or their amplitude. In short, the high and the low notes, the loud and the soft notes, all travel with the same velocity. However many sounds are being transmitted over a given air space, an additional sound can always be transmitted exactly as though the air were still and undisturbed.

Let us see now how sound waves are propagated. Clearly to understand this we cannot do better than consider the action of the tuning fork, the prongs of which beat the air in opposite directions simultaneously. As a prong strikes the air the latter is driven away and condensed. As the condensed air travels outwards the prong recedes, and beating back the air, rarefies it. Thus waves of condensation and rarefication travel one behind the other at the same rate, maintaining the same relative positions with each wave travelling on with equal speed. Fig. 12 shows columns of air that are transmitting such vibrations from three tuning forks, the swiftly moving prongs of which are compressing the air in front of them and in swinging back tend to leave a vacuum behind by which the air is partly rarefied. These alternate waves of compression and rarefaction travel through the air and produce corresponding vibrations in the tympanum of the ear.

Tuning forks give different notes, according to their design. This means, simply, that they vibrate at different periods, so causing fewer or more waves of condensation and rarefaction per second. This will be more clearly understood by referring to Fig. 12, which shows three tuning forks tuned to three different notes.

Supposing a tuning fork to make 100 vibrations a second: at the end of the first second, the first wave will have travelled 1,100 ft.—since this is the rate of travel for sound—and between this point and the tuning fork, there will be 100 sound waves, each 11 ft. in length. As sound waves, no matter what their length, all travel at the same speed through the same medium, it follows that the more rapid the vibrations the shorter is the wave-length. If the vibrations are 1,100 a second, there will be 1,100 waves each 1 ft. in length; if 13,200 a second, the waves will be 1 in. in length, and so on.

NO SOUND IN A VACUUM

Newton showed that the extent of the capacity to propagate sound depends on the elasticity of the medium. In everyday life the elastic body that conducts sounds to our ears is the air. If this is taken away, or if there is any change in its composition, sounds previously audible become inaudible or indistinct. Sound cannot move through a vacuum since there are no molecules to form the compression waves. This can be demonstrated if an electric bell be placed in a bell jar and the air gradually withdrawn. The sound will grow fainter and fainter as the air becomes more rarefied, and finally when a vacuum has been obtained no sound will be heard, although the hammer inside may still clearly be seen banging the bell.

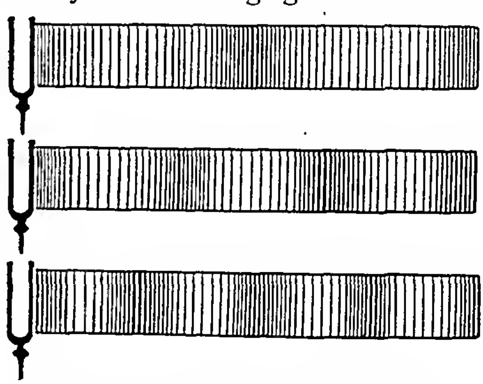


Fig. 12 Three tuning forks vibrating at different rates, thus giving different notes.

Sound travels more quickly in some media than in others. This is because the distances between the particles vary in different substances. Where the particles are comparatively close together there is but little loss of time in the transmission of energy from one particle to another. The particles of a liquid are closer together than those of a gas, so sound travels more easily in a liquid than in a gas; and—for the same reason—more easily in a solid than in a liquid. The velocity of sound in water is 4,900 ft. per second, or more than four times its velocity in air.

GOOD CONDUCTORS OF SOUND

That sound can travel through solid substances may be demonstrated by laying a watch at the end of a wooden table and pressing the ear to the other end. The ticking of the watch will be heard distinctly even though it cannot be heard directly through the air, for sound travels better through 10 ft. of wood than through 1 ft. of air. Even the solid Earth itself will transmit sound, and will transmit it more efficiently than does the air. We all remember reading of Red Indians detecting the approach of their enemies, or of a herd of buffalo, by putting their ears close to the ground and listening.

That sound travels faster through some substances than others can be proved if we place an ear against a telegraph post and get a friend to hit the next post a sharp blow with a stick. In this case we hear two distinct sounds—first that through the wires and the post, and then an instant later the normal sound of the blow transmitted through the air. The reason for the two separate sounds is because of the different velocities of sound in solids and in gases—in this case the air. A similar and more striking test can be made if there is available a long unbroken stretch of iron railing. We get a friend with a hammer to strike the railing a sharp blow a couple of hundred yards away. If we put an ear to the railing two sounds will be heard—one through the railing itself and the other, an instant later, through the air.

Sound travels through granite at 1,664 ft. per second; through lead at 4,030 ft. per second; through pinewood at 11,000 ft. per second. Its velocity through iron is 17,500 ft. per second, or about fifteen times as fast as through air. Steel is obviously more difficult to compress than air—actually it is over a million times less compressible and it is over 6,000 times as dense. Because of this, sound travels at three miles a second in steel.

Sound spreads in every direction—upwards, sideways, forwards, and backwards; with the result that the amount of sound received by a listener placed 50 ft. from its source is only about one fifty-millionth part of the total sound emitted. At twice the distance, that is 100 ft., the wave is spread over four times the area, and only a quarter of the amount mentioned in the first case is received by a listener. Thus we see that with every increase in the distance of the hearer from the source of sound, the amount of energy diminishes enormously. This is expressed more scientifically by saying that the intensity of a sound varies inversely as the square of its distance. This law of inverse squares applies equally to all wave-motions in general, holding good for Sound, Heat, Light, and Gravitation.

EFFECTS OF FROST

When considering the intensity of sound we have also to take into consideration the density of the medium through which the waves are transmitted. On a frosty night sounds are heard more clearly and over a greater distance

because the air is denser. On the other hand, a revolver fired on a high mountain, where the air is less dense, gives a report that may be no louder than that of a small cracker fired at sea level.

Everyone has noticed circumstances indicating that sound takes an appreciable time to travel over any distance. If the firing of a gun is watched from a distance, the moment of firing will be signalised by the flash from the muzzle. The sound of the explosion will be heard, a little time afterwards, however. During a thunderstorm the noise we call thunder, which is actually the noise of the electrical discharge known as lightning, is heard some time after the lightning flash has been seen. As light travels almost instantaneously it is always observed before the sound that accompanies it.

This delay in the sound-wave reaching the ear gives a rough guide as to the distance of the source of the sound.

SPEED OF SOUND

The speed at which sound travels is affected by the temperature and actual constitution of the atmosphere. (The former affects the atmosphere's compressibility, and the latter—by the amount of water vapour it contains—its density.) The reason for this is that air is an elastic medium, and the greater the elasticity, the more quickly will the molecules tend to return to their original condition after the passage of the wave. Consequently, the velocity of the transmitted wave will be greater. An alteration of 1°C. in the temperature will affect the velocity of a sound-wave by 2ft. per second. At a temperature of 1°C. sound travels at about 1,087 ft. per second, so that at 20°C. the velocity will be increased to 1,127 ft. per second. As an average velocity at normal temperature we can take a figure of 1,100 ft. a second or 750 miles an hour. We can prove this roughly ourselves by watching blasting operations, or a gun being fired at, say, a distance of five miles. The sound of the explosion will not reach our ears until about 25 seconds after the flash is seen.

The knowledge of the velocity of sound was used during the War to determine the position of hidden enemy guns. In one method of "sound-ranging", as it is called, three microphones were used, placed, say, half a mile apart (Fig. 13). In this diagram is shown an aerial view of an area in which the opposing armies were operating. The inset A, top left, is a map of the same area. When the enemy gun, hidden in the trees in the bottom left corner, was fired, the sound vibration passed the microphones and the resulting currents registered at a central observing station (B Fig. 13) by actuating delicate galvanometers. From the needle of each of these a spot of light was reflected on to a piece of sensitised film mounted on a rotating drum. Time-signals were also recorded on the film alongside the light-trace from the galvanometer. Owing to their varying distances from the source of the sound, the microphones recorded the passing of the sound wave at slightly different times (C Fig. 13). By comparing the differences in these times the position of the enemy gun could be ascertained, and when this had been done the information was communicated to our artillery for the "necessary attention and action".

FREQUENCY OR PITCH

As sound-waves are a periodic phenomenon, they are subject to the ordinary laws of harmonic motion, by which one sound-wave may differ from another, and therefore one musical note from another, in certain essential properties. The frequency, or "pitch",

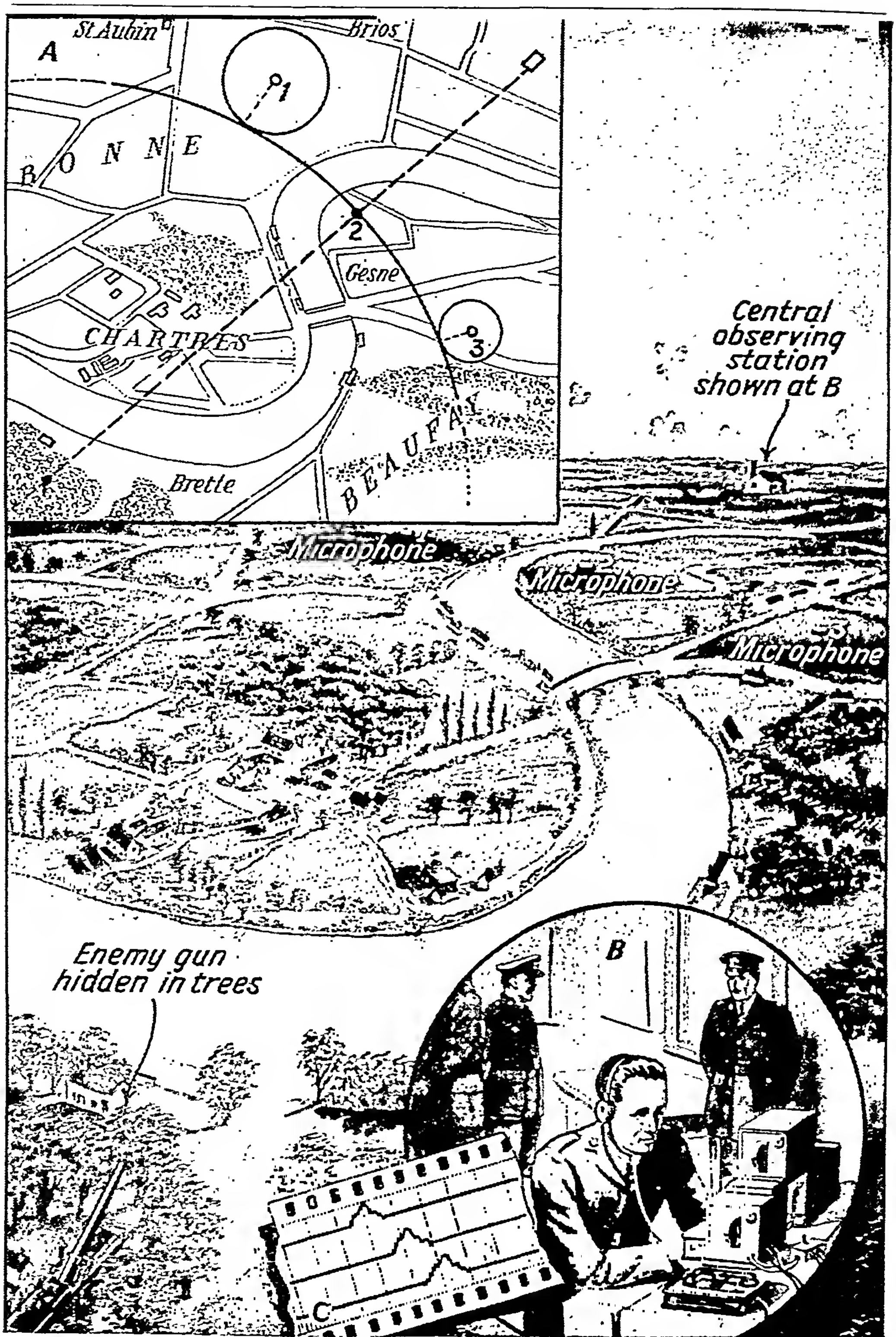


Fig. 13. How the exact position of an enemy gun may be calculated from sound waves.

of the waves of compression and rarefaction, alternately pressing inward and releasing the tympanum, determines the *note* received by the ear. Frequency is governed by the arrival of a greater or less number of impulses in a given fraction of time and for convenience, frequency is referred to in terms of "cycles per second", or "c.p.s."

LIMITATIONS OF AUDIBILITY

As the frequency increases the waves become shorter, and consequently the pitch rises, until it may ultimately become so high that it is inaudible to the human ear. Exactly as the eye has its limitations as to what wave-lengths of light it can perceive, so has the human ear its limitations of sounds that are audible. When a toy musical top is set spinning at a very high speed no "music" is heard, but as the speed drops we hear first a very high note, the pitch of which drops as the speed of the top decreases. Finally, a very low note is produced, and although this apparently ceases, vibrations continue to be produced but of too low a "pitch" to be detected as a sound. In sound the audible limitations differ slightly with different people. Generally speaking, the lowest frequency audible is about 16, and the highest about 30,000 or 40,000 cycles per second. Some people can hear sounds of higher frequency than others—some are able to hear a canary singing very high notes when to others, whose ears are not so responsive to these very high frequencies, the bird seems to be silent. Sounds that are often beyond the range of many people's ears include the squeak of the bat and the chirps of the cricket. Sounds that are inaudible to the human ear, but are easily audible to a dog or a horse, can be produced by Galton's whistle in which the note is varied by the movement of a plunger, as in the trombone.

The lowest note heard by the average person is caused by waves 65 ft. in length with a frequency of 16 cycles per second. The highest are caused by waves $\frac{1}{3}$ in. in length with a frequency of 38,000 per second. On a piano the range of notes represents vibrations of from about 30 to 3,000 per second.

So beautifully is the mechanism of the ear adjusted that as minute a difference in frequency as 1 in 400 c.p.s. can be appreciated, but, curiously enough, only for those notes that are within the compass of the human voice. Within the range mentioned are the numerous tones we hear in a musical performance—the more rapid the frequency the more acute the tone or pitch. This may be seen, for example, by comparing the first and second graphs in Fig. 23. The former shows a record, as made on the Low-Hilger Audiometer (see page 264) of a violin E, frequency 689 c.p.s., and the latter of violin D, frequency 307 c.p.s.

SPEED AND PITCH

Probably everyone has noticed the peculiar sound-effect experienced when standing on a station platform as an express dashes through emitting a whistle. As the train approaches us the pitch of the whistle steadily rises and after it has passed us and is receding, the pitch lowers. The same thing may be noticed when passing a ringing bell in a motor car that is travelling at a fair speed. We have seen that the pitch of a note depends on the frequency with which the vibrations strike the ear. In the case of the express, the frequency is increased as the engine approaches because the sound-waves have added to their normal speed of travel the speed of the engine; the rate of travel of which, in the case of an express, is about $\frac{1}{10}$th the speed of sound.

An illustration of what happens is afforded by a gun in action firing shells

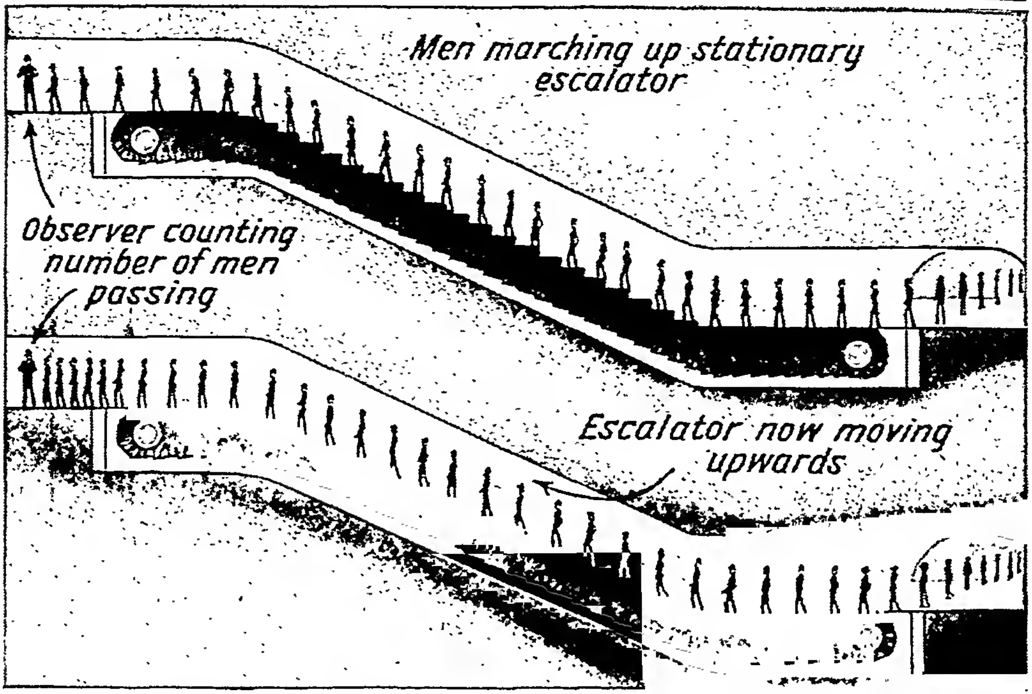


Fig. 14. Illustrating how pitch and speed of sound interact (see text). Fewer people appear to pass the observer at top of stationary escalator than at the top of a moving one.

at a target at fixed intervals of time. If the gun is mounted on a moving platform that advances, say, 500 yards between the firing of each shell, it is obvious that the shells will fall more frequently on the target than if the gun were to remain stationary in its original position. Similarly, if the gun retires 500 yards between the firing of each shell the shells will strike their objective at correspondingly greater intervals. Whether the gun or the target is in motion is immaterial, for the result will be the same in either case. Another illustration of the principle involved is shown in Fig. 14. Here, in the top drawing, passengers are seen walking up a stationary escalator. Fewer men appear to pass the observer at the top than is the case when the escalator is moving.

Actually, therefore, in the case of the train, the pitch of the whistle will be the same to the engine driver and the bystander only at the moment when the train is actually passing the platform.

The phenomenon is particularly noticeable when a high-speed aeroplane is flying low and passes overhead. When the Schneider trophy race was broadcast, for instance, the note of the machines, travelling low at over 300 miles an hour, showed a drop in pitch of nearly an octave. This principle was discovered by C. J. Doppler, an Austrian physicist in 1842, and we shall refer to it again in our section on Light.

In a stringed instrument the pitch is altered either by decreasing the length of a string or by increasing its tautness, for a taut string vibrates more frequently and produces a higher note than a loose one (Fig. 15). A simple musical note is the result of a continuous, rapid, and uniformly recurring series of impulses. For example, the note A^1 on a piano has a frequency of 439, or in other words when this note is struck the sound-waves reach the ear of the listener at 439 cycles per second. C^1

has a frequency of 522 c.p.s.; C^{II} 1044 c.p.s.; and so on.

There are other characteristics of a musical note in addition to pitch. One of these is the quality, often called the *timbre* or "tone-colour", by which we are able to distinguish a note sounded on, say, a violin and the same note sounded on a flute. H. von Helmholtz, the German scientist, showed that timbre is due to the number and intensity of the supplementary notes, called "overtones" and "*harmonics*", *that* are also given out by the string. These overtones are present in all musical notes and give them their characteristic timbre.

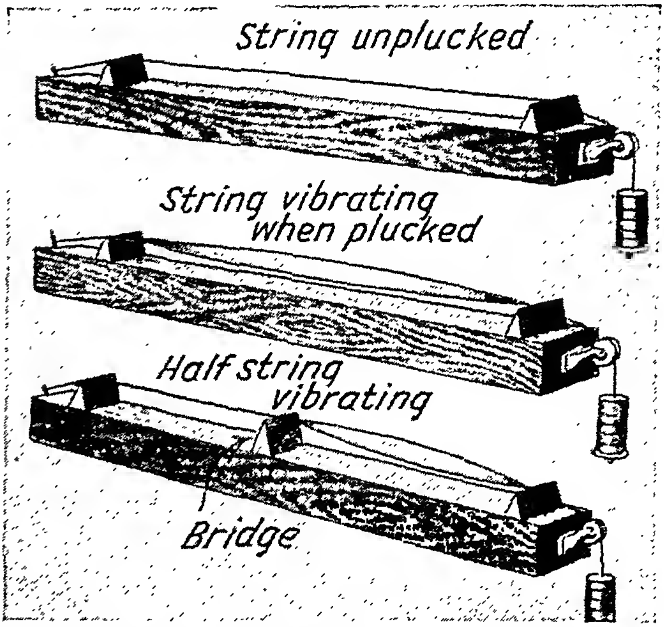


Fig. 15. Showing how a plucked string vibrates. By decreasing the length of a string, by the intervention of a bridge, as shown in the drawing, or by pressing on it with the fingers, as does the violinist, the pitch is altered.

Overtones arise because a string vibrates not only as a whole but in parts as well—in two parts, giving vibrations from each half (A Fig. 16); in three parts, giving vibrations from half of two-thirds (B Fig. 16); in four parts, giving half of half, and so on. Thus, in addition to the original keynote, say C, we have the octave C (half) the G in the octave above (half of two-thirds) and the next C (half of half), and so on. We thus see that the number of vibrations is doubled by halving the original length of the string—actually, the vibrations vary inversely to the length of the string—as every violinist knows. As we have already mentioned, a similar effect is obtained by altering the degree of tension of a string, and this variation depends on the square root of the tension applied. Thus, to cause a string to vibrate twice as quickly the tension must be increased four times; to cause it to vibrate three times as quickly the tension must be increased nine times, and so on.

In addition to length and tension, the diameter of a string is another factor that *affects the* note it gives out. Given

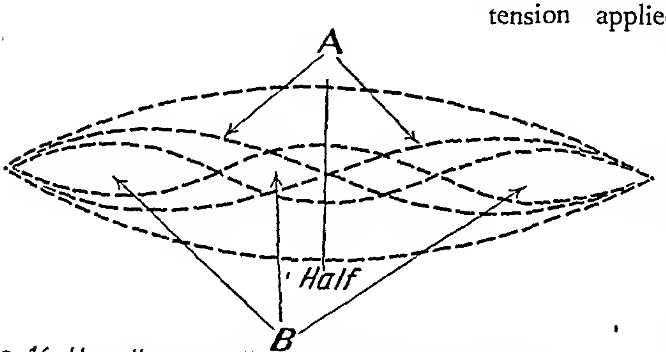


Fig. 16. How "overtones", or supplementary vibrations of a string, arise. (See text for full explanation.)

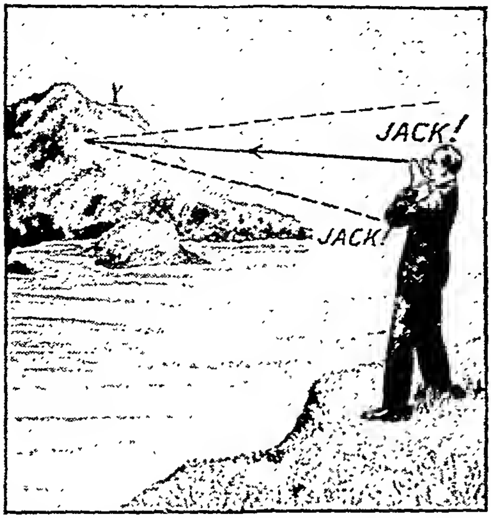


Fig. 17. An echo is merely sound waves turned back after they have struck a reflecting surface. It proves that sound takes time to travel.

the same length of string and the same degree of tension, a string of double the diameter will give a note of an octave lower, for it vibrates only half as quickly as a string half of its diameter. Two strings of similar lengths, tension, and diameter, but of denser material, will vibrate differently, the heavier one vibrating less rapidly than the other. A violin G-string is a gut string closely wrapped round with fine copper or silver wire, and because its density has thus been increased it emits a deeper note even than that of a thick gut string at the same tension. The number of vibrations varies inversely to the diameter of the string and inversely to the square root of the density of the string.

Yet another characteristic of a musical note is its intensity—whether the sound is loud or soft—and this depends on the amplitude of the vibrations. Amplitude may be said to be the extent to which each particle in the line of transmission oscillates to and fro about its mean position of rest. For the least audible sound the extent of motion of the air particles is about one ten-millionth of a centimetre on each side of their mean position. If the amplitude is increased, the sound becomes louder and can be heard at a greater distance—in other words, intensity is dependent on the extent of the vibrations. Notice in the lowest graph (violin G) in Fig. 23, how the amplitude decreases towards the right-hand side.

SENSITIVITY OF THE HUMAN EAR

The knowledge of these several properties and characteristics of sound-waves enables us the better to realise the wonderful delicacy of the human ear. All these vibrations are interpreted, without conscious effort on our part, into pitch, timbre and amplitude, by the marvellous mechanism of the tympanum and its connected parts.

If the end of a rope is shaken, a wave travels along it as a "crest", and when the wave reaches the other end of the rope it is reflected and returns as a "hollow". In a similar manner, sound-waves may be reflected and refracted, exactly as light-waves are. When this occurs they are always reflected at the same angle as that at which they strike the surface—or to express it more scientifically the angle of reflection is equal to the angle of incidence, a law that also applies to all other wave-motions. Theoretically, this is what should happen when a billiard ball strikes the cushion of the table, and no doubt many billiard players often wish that practice was more often in accord with theory than it is.

In the case of rays of light striking a mirror we see "behind" it a reflected image of the objects that are really in front. When driving in a car we hear the sound it makes reflected from the fences and trees we pass, for sound does not necessarily require a flat unbroken surface for its reflection. Even isolated posts will throw back a "zipp" of sound.

A length of railings gives a quick succession of reflections almost like the ticking of a clock, or sometimes when the car is nearer to them the reflection resembles the sound of a machine-gun in action.

Reflected sound is termed an *echo*, and the length of time required for the sound to be reflected back to its source depends on the distance of the reflecting surface. The echo is another illustration of the fact that sound takes time to travel. The sound made by a person shouting has to travel some distance until it strikes a surface that has the property of reflecting back, or echoing, this sound. Then it has to travel back to our ears and an appreciable time is taken on each journey, resulting in our hearing the repetition of the original sound some little time after it originated (Fig. 17).

There is a curious phenomenon known as the *persistence of sound*, due to the sensation of sound persisting in our brain for $\frac{1}{10}$ second after the sound-waves cease to reach the ear-drum. Thus, if the walls of a room are more than 50 ft. away, a reflection of a voice can be heard as an echo. In a smaller room than this, however, the reflected waves blend with the original sound waves and reinforce them, so that a voice will sound louder than in the larger room.

OVERCOMING ECHO

Echoes sometimes cause serious problems to architects, for they may interfere with the acoustic properties of churches and theatres, and of halls used for public speaking or musical performances. The problem that has to be overcome is to prevent echoes that would cause blurring of the music, owing to the time taken for the sound to travel from the source to some reflecting surface and back to the listener's ear being longer than the time taken for sound-waves to travel to the listener direct. Such a condition causes the echo of one note to be heard almost at the same time as the next note, travelling direct, strikes the ear. The result is a distorted sound that is musically unpleasant. To prevent echoes in buildings it is necessary to break up those sound-waves that do not travel directly from the speaker to the audience. Sometimes this is done by stretching wires over the heads of the audience or by an arrangement of curtains or partitions. Even the design and the composition of the upholstery used on the seats in a hall have an appreciable effect on echoes.

CONCENTRATING SOUND

Obviously, a sound would travel to a greater distance if it could be prevented from spreading in all directions. If we take the 12-volt bulb out of the reflector of the headlight of a motor car we are surprised to notice what a comparatively feeble light it gives, as compared with the strong dazzling beam when in position in the headlamp when all the rays of light are conserved and made to travel in the same direction. The principle of the echo may be employed in several ways by using a series of reflections, as in the case of the sound that is reflected from more than one surface in the famous "whispering gallery" in St. Paul's Cathedral, London (Fig. 18). This same principle of repeated reflection is used in the ear-trumpet and in speaking-tubes generally. We get a somewhat similar effect by the use of a megaphone, by which the voice can be carried to a greater distance than would otherwise be the case. We use the same principle in a motor car horn, a ship's syren, a stethoscope, and other similar devices.

The principle of the echo is also made use of to measure the depths of the sea

by an interesting instrument called the "Echometer". The importance of such an instrument can best be appreciated by considering the figures, published periodically, showing the causes of loss of ships at sea. These figures show that even during the past few years, when numerous scientific aids to navigation have been made available, more than 50 per cent. of the losses have been due to stranding and kindred causes. This is a clear indication of the necessity for apparatus that will show the navigator the depth of water under his ship.

There are several types of Echometers, but we take the Marconi device as representative of them all. Irrespective of the speed of the vessel or weather conditions, and no matter how quickly the ocean bed may vary, this device gives an immediate record of all depths between 2 and 360 fathoms under the keel of the ship. It is a separate unit, capable of being operated from a small battery, and is silent in operation. With this device the nature of the sea bottom—i.e. whether hard or soft—can also be ascertained. The instrument relies for its efficiency on supersonic waves (that is, waves that are of a higher frequency than can be detected by the human ear) that are concentrated into a beam. The navigating officer in the chart-room is able to discover the depth without

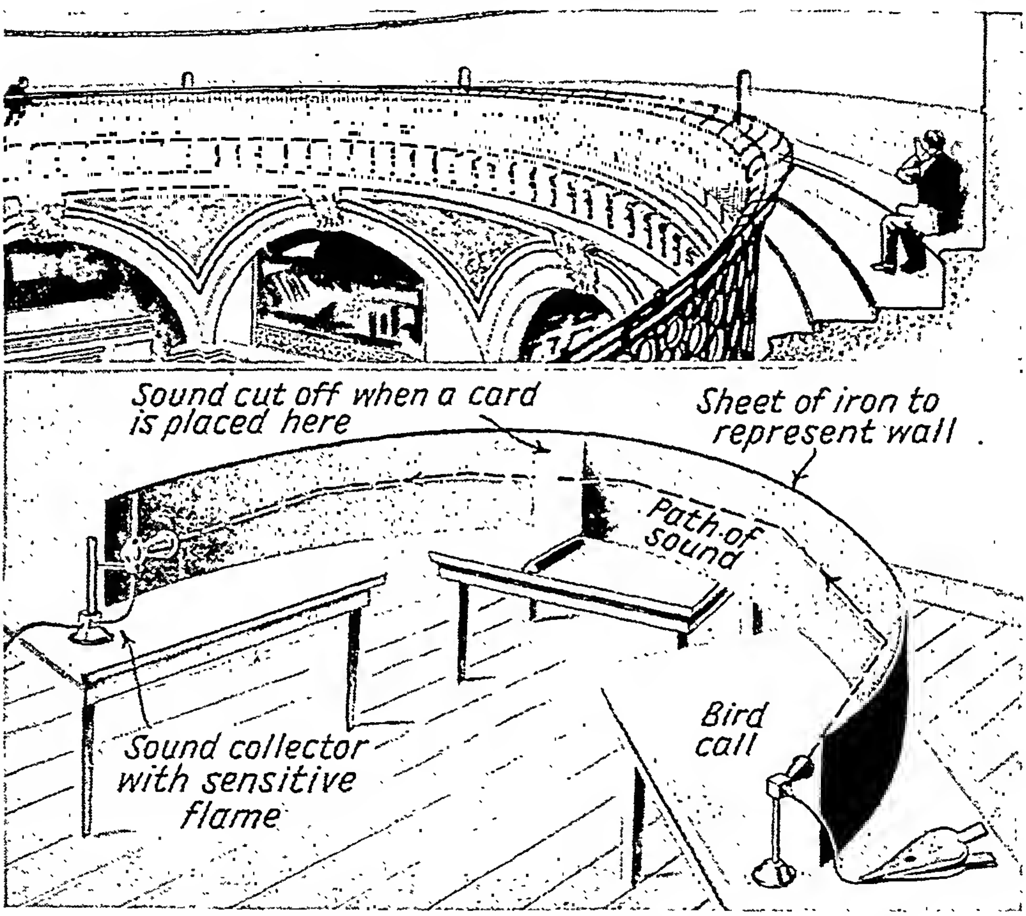


Fig. 18. The reflection of sound accounts for the phenomenon of the Whispering Gallery at St. Paul's Cathedral. The principle is illustrated in the lower drawing.

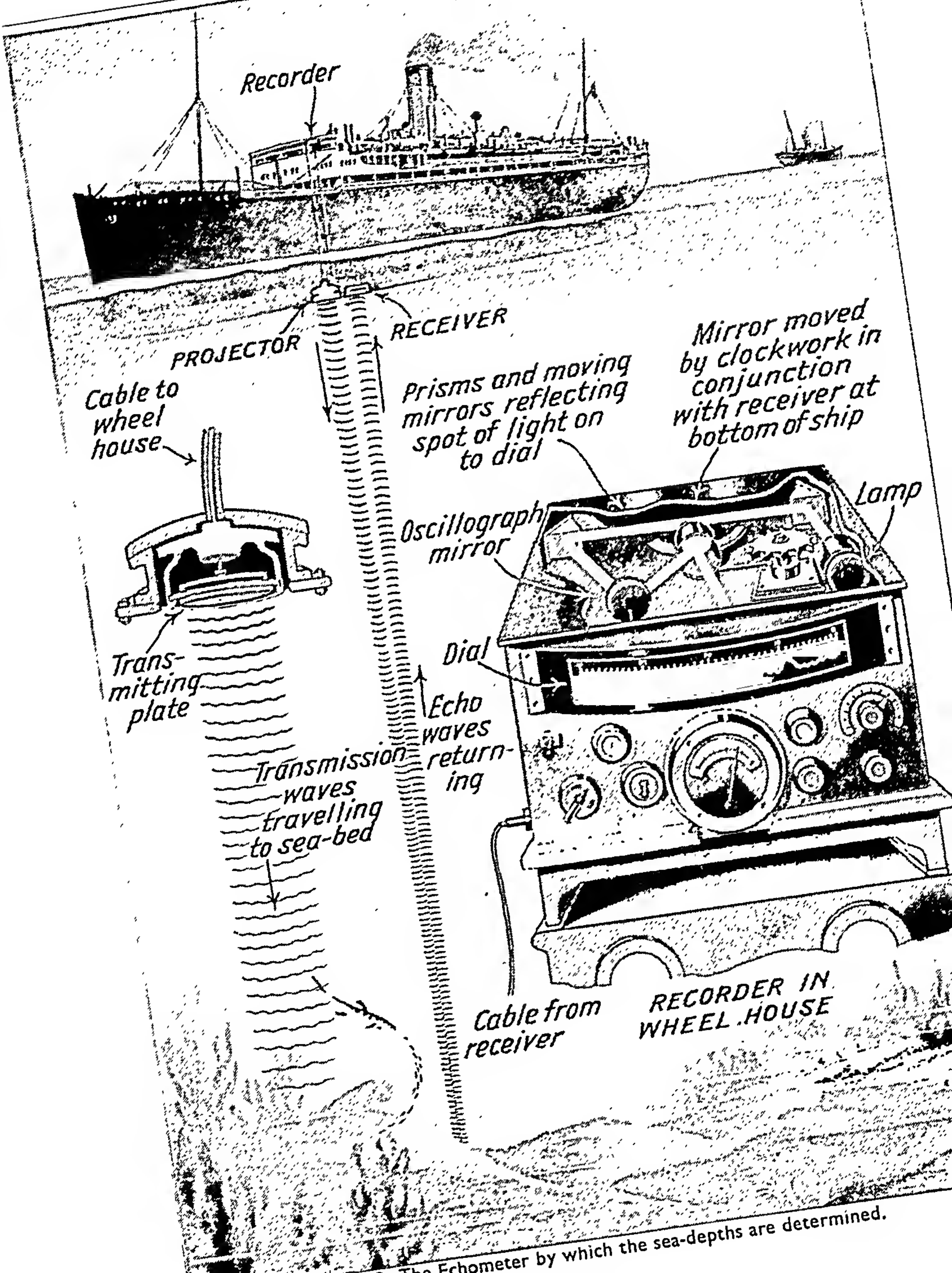


Fig. 19. The Echometer by which the sea-depths are determined.

having to take soundings by the old laborious method. Before the automatic echo-sounding device was introduced there was always a certain reluctance to take soundings frequently, particularly in rough weather when the men taking the soundings were exposed to the fury of the elements. Further, the old method involved considerable loss of time since it was often necessary to slow-down or stop the ship while soundings were being taken.

THE ECHO SOUNDING DEVICE

Briefly, the Echometer consists of a projector housed in the bottom of the ship. When a "transmission" is to be made an oscillating current is applied for an instant across two thick steel plates. This current causes the outer plate to vibrate at high frequency, imparting a wave motion to the water. The signal travelling to the bottom of the sea is reflected back again and strikes the projector. A reverse process then takes place and a small voltage is set up in the circuit connected to the projector. The measurement of the depth of water is thus a question of measuring the interval of time between the transmission and the reception of the echo; a task that is automatically carried out by the instrument itself, the result being recorded on a moving strip of paper (Fig. 19).

We have already mentioned that the velocity of sound in water is about 4,900 ft. per second, yet so delicate is the Echometer that depths of only a fathom (6 ft.) can be measured with it. Near the Sandwich Islands a depth of 4,500 fathoms has been recorded, the sound requiring about 11 sec. to make the double journey. Two soundings of 5,900 fathoms near the Phillipines gave a time interval of 13·90 sec. At the other end of the scale are the 30·35 fathoms of Windermere and the 7 fathoms of Esthwaite, records recently obtained by a party of young scientists investigating the depths of the Lakes with the Echometer.

Exactly as sound may be reflected, so, too, can it be refracted or bent, when passed from one medium to another of different density. If a piano is being played in a room, the sound is transmitted by the air to the wall, through which it passes to continue its way through the air of the next room. The direction of travel of the sound-waves in the second room is different from their direction in the first room, for they have been refracted when passing through the intervening wall.

Sound-waves may be brought to a focus, as light-waves are, by refraction. This has been shown in an experiment originally performed by Lord Rayleigh. He filled a balloon with carbon dioxide and placed a watch on one side of it. The sound of the ticking was brought to a focus at a definite point on the other side of the balloon (Fig. 20). In the experiment the gas in the balloon corresponds to a telescope lens, refracting the sound-waves in a manner similar to that in which the lens refracts the light from a star, bringing the rays to a focus at the eyepiece end.

WORLD'S LOUDEST SOUND

The world's loudest sound was caused (27th August, 1883) by the eruption of Krakatoa, already mentioned in an earlier section of this book. The sound of the explosion, by which two-thirds of the island were torn away, was heard over nearly one-eighth of the Earth's surface. Preliminary sounds, resembling the discharge of artillery, were heard on the coast of Borneo and even further away. In Achin, in the extreme north of Sumatra and 1,073 miles distant, the people thought that an invasion was being attempted and

troops were put under arms to repel the supposed attack! At Singapore, 522 miles away, two steamers were despatched to sea, it being thought that some vessel was firing guns as a signal of distress. The noise was heard in places 3,000 miles from the scene of the explosion. To the North of Krakatoa, it was heard at Bangkok, in Siam; to the south, in South Australia. To the west, the sounds reached far beyond Ceylon, to the Chagos Islands and Rodriguez, in the Indian ocean. They arrived at the last named island about four hours after the explosion had taken place. We shall perhaps more readily appreciate the magnitude of the distances covered by the sound if we imagine the explosion had taken place in the northern hemisphere. Had Krakatoa been situated in the Canary Islands the sounds would have been heard in the United States and in Britain. Had it been at the North Pole it might have been heard in France and on the shore of the Caspian Sea.

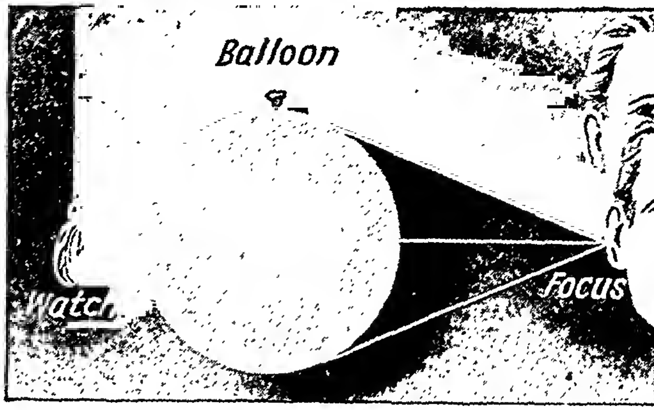


Fig. 20. How sound-waves may be brought to a focus by means of a simple gas-filled rubber balloon.

The whole atmosphere of the Earth trembled from the resulting air-waves that completely encircled the globe, moving outward in an ever-widening circle until they reached 90° from Krakatoa. Thereafter, they continued to advance but now contracting to a point at the opposite side of the Earth to Krakatoa. From here the wave returned once again to Krakatoa and, having reached its place of origin, travelled again to the opposite side. This performance was repeated at least seven times, each time with diminishing force.

A rather unexpected characteristic of sound is that in some circumstances it can actually be felt. If we stand near a gun when it is fired, a disturbance of the air will be felt at the moment we hear the sound. In the case of a large explosion the disturbance is sufficiently great to cause damage, such as broken windows, etc. Another striking example of this is the effect of playing very low notes on an organ. No doubt we have all been in a church or a concert hall where these low notes have been played, and have felt a throbbing of the air and in some cases of the actual building. Although no such disturbances are felt with the majority of sounds, they are nevertheless present and would be felt were our senses sufficiently delicate to detect them. in all cases.

Such disturbances can be recorded, however, and in fact it is they that make possible the gramophone and the talking-picture, the sounds being recorded on "records", and on film respectively.

SOUNDS MAKE SHAPES

One of the simplest ways of producing a record of sound is by drawing a vibrating tuning-fork over a sheet of paper so that a piece of black-lead from a pencil attached to one prong will leave behind it a wavy line as shown in

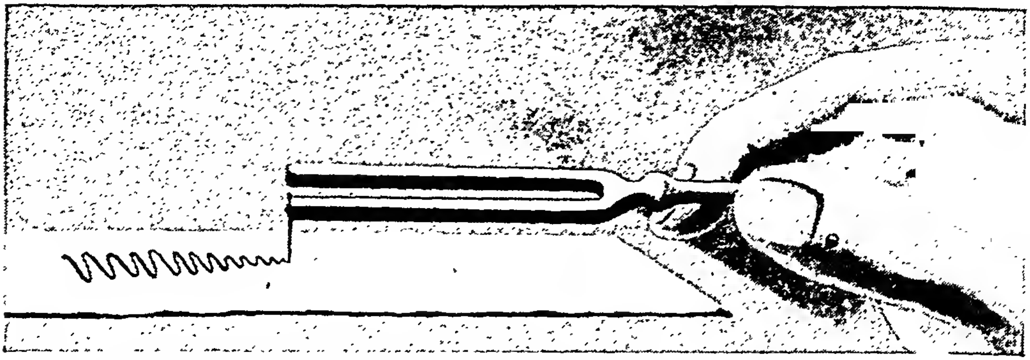


Fig. 21. A simple, but elementary, way of making a record of sound-vibrations by attaching a pencil-lead to a tuning-fork. An advance on this method is shown in Fig. 22.

Fig. 21. This is only a crude arrangement in which the prong soon comes to rest, its energy being overcome by friction. A more satisfactory arrangement, suggested by Duhamel in the early days of sound-recording, is that in which the friction is reduced by using smoked paper mounted on a revolving drum, the pencil-lead being replaced by a stout bristle (Fig. 22).

In 1856, many years before the invention of a machine that would record and reproduce sounds, Léon Scott invented an instrument by which the vibrations produced by speech could be recorded graphically on paper. This device, called the Phonautograph, consisted of a conical metal trumpet or horn, across the smaller end of which was stretched a membrane. To this was attached a light stylus that left a record of the vibrations of the membrane on a blackened cylinder rotated by hand. When any sound was produced near the open end of the horn, the impulses reflected from its internal surface were concentrated on the membrane, throwing it into corresponding vibrations and recording the sound on the prepared paper.

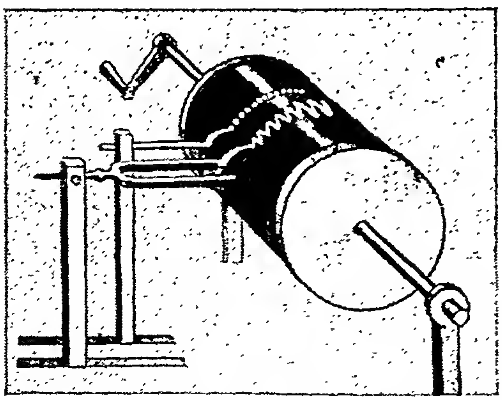


Fig. 22. Another method of recording sound-vibrations. A bristle attached to a tuning-fork will mark a piece of smoked paper, mounted on a hand-operated revolving drum.

MODERN RECORDING

Sound-waves to-day are recorded on a similar principle but by much improved apparatus. In the Low-Hilger Audiometer the pressure-variations of sound-waves are recorded as they impinge upon an extremely light diaphragm of celluloid, rubber, or other material—the material used depending upon the degree of sensitivity required. This diaphragm carries a tiny mirror and a beam of light from a lamp falling on it is deflected to a photographic film mounted on a shallow revolving drum (Fig. 23).

This is enclosed in a specially designed camera-box provided with an automatic shutter arranged to expose such parts of the film as may be required. Records such as are made by this apparatus are depicted in the inset.

As we have already seen, the records appear as long wavy lines, made up of

what may be termed "hills and valleys". The height of the hills and the depth of the valleys indicate the amplitude and this varies according to the intensity of the disturbance that causes the wave. The number of hills and valleys in a given space on the record gives the frequency, on which the pitch of the note depends.

The human voice, the strings of a piano, the reeds of wind-instruments, and all other sounds have characteristic records. Indeed, it would not be difficult for a student of sound-waves to state the origin of any sound-record merely by studying the trace produced. The overtones appear as additional and more rapid vibrations, forming secondary frequencies in every complete wave-cycle, and may be likened to the independent ripples that travel over the surface of the larger waves in the ocean.

Léon Scott, whose work we have mentioned, did not suggest that the sounds giving rise to the traces in his recording instrument could be reproduced. Obviously, however, if there could be a reversal of the process so that the record on the paper could be made to actuate the stylus and the membrane, they would throw the air within the horn into corresponding vibrations. A few years after the invention of the Phonautograph, however, a M. Cross deposited at the Academy of Sciences in Paris a sealed paper. This was opened after Edison had patented the phonograph in 1877, and was found to contain suggestions of how the sounds recorded by the Phonautograph might be reproduced.

ORIGINS OF THE GRAMOPHONE

Edison's attention was drawn to the possibility of inventing a "talking machine" when he was working on high-speed automatic telegraph instruments. In this connection, when experimenting with embossed strips, he noticed that if these strips were moved rapidly beneath a metal pen so as to vibrate

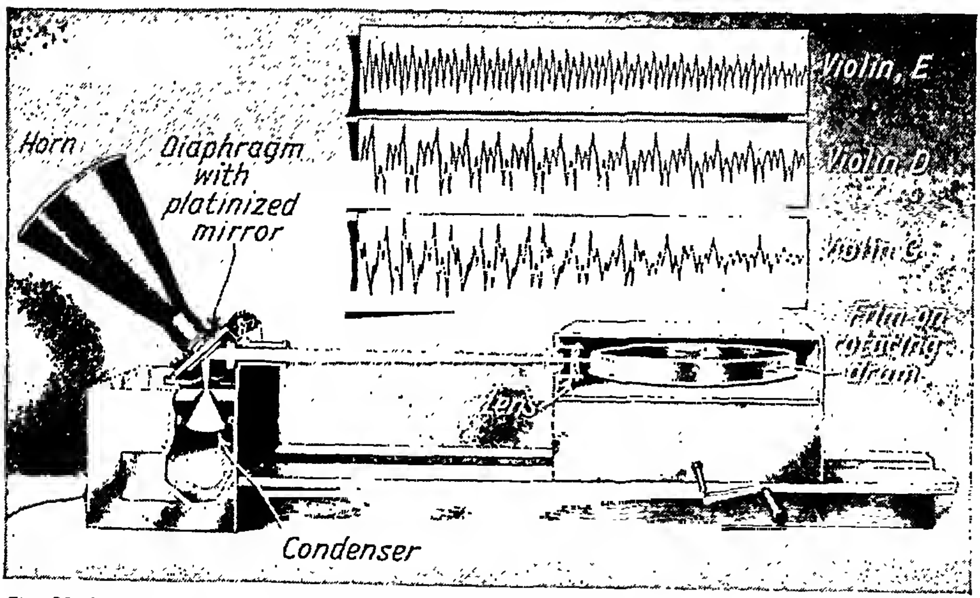


Fig. 23. The Low-Hilger Audiometer which is used for recording sounds. The method is explained in the text. (Inset) Three records made from violin notes, showing clearly the different frequencies and decreasing amplitude of the sounds made by the three violins.

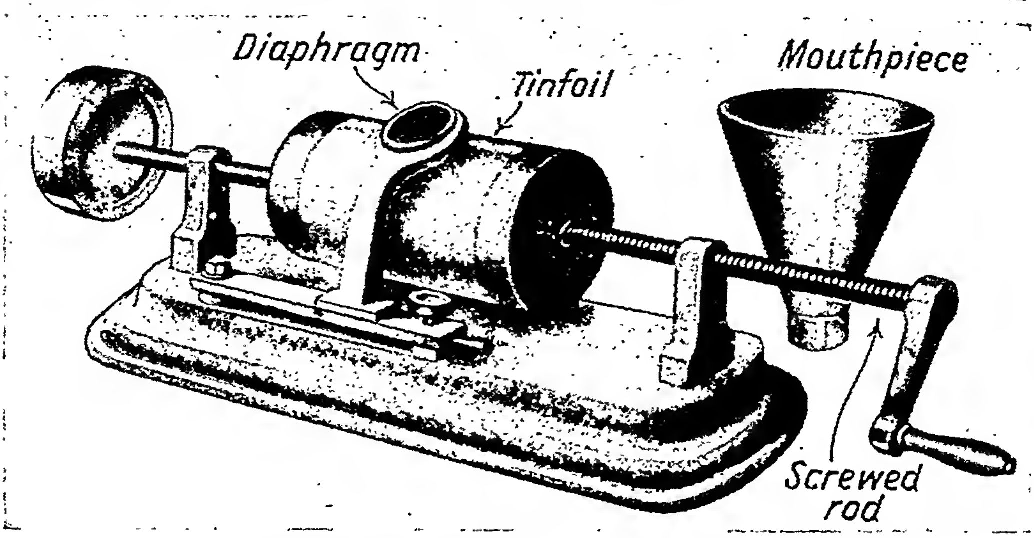


Fig. 24. T. A. Edison's "Talking Phonograph", ancestor of the present day gramophone.

it, the pen produced a peculiar sound. This led him to the idea that undulations could be made on the strips and arranged in regular form so as to cause a diaphragm to vibrate and so produce certain sounds. From this beginning he was led on to the idea that the undulations might be produced by the sounds themselves, and he started to experiment on these lines.

Edison's efforts resulted in the production of the "talking phonograph" (Fig. 24). This consisted of a mounted diaphragm so arranged as to operate a small steel stylus, bearing on a solid brass cylinder about 6 in. in length and 4 in. in diameter. The diaphragm was supported by an adjustable bracket, and carried the steel stylus on a small flat steel spring, there being a piece of india rubber between the two to modify the action. A spiral groove was cut in the circumference of the cylinder from one end to the other, and a corresponding thread was cut in the shaft on which it was mounted. Thus when the shaft was turned by a hand crank the cylinder revolved and receiving a forward or backward movement along the shaft, the stylus was able to describe a spiral circuit around the cylinder surface.

The first records were made with the stylus lightly pressing on tinfoil wrapped around the cylinder, the crank being turned so as to bring fresh tinfoil beneath the stylus. Sounds made in the mouth-piece caused the diaphragm to vibrate, the stylus marking the soft tinfoil with indentations of different depths, corresponding to the amplitude of the vibrations of the diaphragm.

EDISON'S FIRST GRAMOPHONE

When the recording was done and the tinfoil covered, the cylinder was wound back to the starting point, and the record was then "played". The diaphragm clearly repeated all that had been spoken into the mouth-piece when the record was made. Into the trumpet of his first experimental model Edison spoke the rhyme "Mary had a little lamb", and when the cylinder was turned back, the words were heard like a faint echo. He applied for a patent on Christmas Eve 1877, but was too busy to further develop the invention at that time.

A. Graham Bell, the inventor of the telephone, his brother Dr. Chichester

Bell, and an assistant S. Tainter, undertook to improve it. After long experiment they found that paraffin wax, with a small admixture of some other substances, was a better material than tinfoil for recording the impressions. A cutting stylus bearing on this cut out a fine groove that gave a perfect record of every degree of inflection of a speaker's voice. The new form of the instrument was called the graphophone, to distinguish it from Edison's phonograph. In it the cylinder did not move forward as in the phonograph, but instead the diaphragm was made to move parallel to the revolving cylinder. The cylinder was driven by a treadle, like a sewing-machine, and there was an ingenious arrangement by which the speed could be controlled and maintained constant.

Edison later returned to the subject, and using solid wax cylinders with a perfectly uniform surface, obtained a great increase in the clarity of speech and tones of music. These later instruments were driven by small electric motors, and the speed was regulated by a centrifugal governor. The wax cylinders were capable of being replayed a thousand times or more without deterioration. Writing of the usefulness of the phonograph not many decades ago, an author claimed that the new invention would enable "the songs of a fine singer in all their modulations to reach people in distant lands, or be audible to future generations. Thousands of people in England have heard with their ears, through Mr. Edison's instruments, songs and speeches and pieces of concerted music, sung, said, or played in America months before. Music can be bottled up, so to speak, without the consent of the originators; and, indeed, it is said that an eminent prima donna has applied for an injunction to restrain certain phonographers from reproducing her vocal triumphs with their instruments. A speech of Mr. Gladstone's delivered in England, has been phonographically heard in New York with great applause". How surprised the writer of those words would be if he could see the modern electric record-changing gramophone built in a console with a super wireless set!

Whilst Edison and Bell were perfecting their phonographs and graphophones, Émile Berliner, an American of German extraction, revolutionised the system on which they were working. He had already greatly improved the telephone, over which Edison and Bell had long

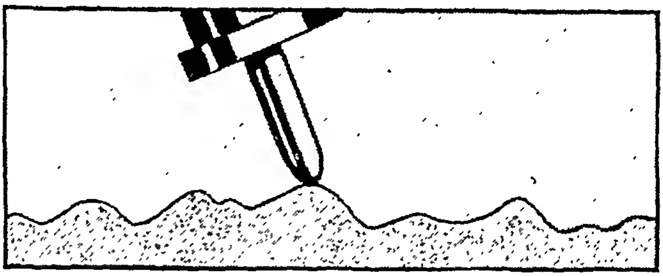


Fig. 25a. Needle in contact with record made on the early "hill-and-valley" principle of sound-recording.

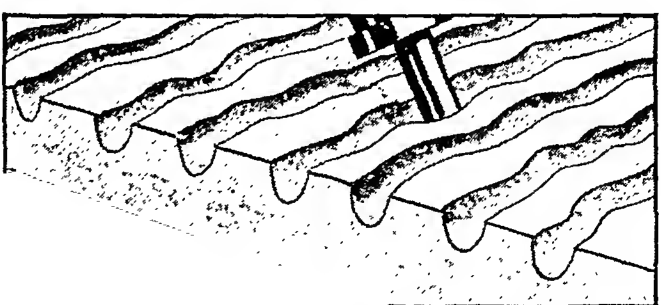


Fig. 25b. "Wall" grooved record of the type invented by Emile Berliner. The needle has a side-to-side movement.

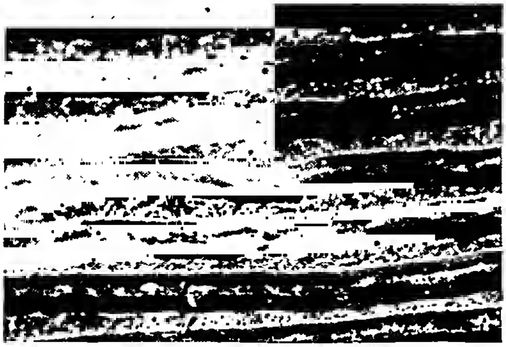


Fig. 26. Grooves of a "Wall" gramophone record.

been fighting, and in 1887, by inventing the gramophone, he again stepped in and snatched from them the prize for which they were struggling. Not only did Berliner's gramophone use flat discs, which are more convenient in shape than cylindrical records, but its movements were more simple. It required only a single movement to spin the turntable, whereas in the phonograph two movements were necessary—one to rotate the cylinder and the other to move the reproducer along the spiral groove on the cylinder. Further, Berliner's gramophone was free from a fault common to both the Edison and the Bell systems. Edison and Bell were using a method of recording sound, whereby the indentations of the cutting stylus were impressed on the floor of a groove in the record. If we could see a magnified section of such a sound track we should notice that the track resembled a succession of hills and valleys, caused by the varying impressions of the stylus on the wax (Fig. 25a).

Berliner saw that this early method was unsound, for the reproducing needle would jump from the top of one "hill" to the next and completely skip over the "valley"; not only were sound-vibrations missed but a good deal of unnecessary noise was produced as well. Berliner set to work in 1887 and produced something quite different from the "hill-and-valley" cut. In his device the depth of the grooves in the record are always the same, with the floor of the groove level for the whole distance around the disc. The sound-waves are cut into the walls of the groove, so that instead of the needle having a vertical movement it has a side-to-side movement (Fig. 25b).

Berliner's method represented a considerable improvement over the early "hill-and-valley" recordings. It gave far more accurate reproduction with less scratch and as the weight of the sound-box was carried on the bottom of the groove, records were subjected to less wear. In consequence it was possible to use mild steel needles which were far cheaper than the agate or sapphire needles necessary with early "hill-and-valley" recordings.

Unfortunately steel needles are themselves worn in playing a record and experiments have proved that the "shoulders" which are formed in this way on their points, do seriously cut the shellac grooves. That is why a steel needle should only be used once.

NEEDLES MADE OF JEWELS

Modern researches in recording are therefore, tending to revert to the "hill-and-valley" method. New ways of suspending the sound-box have been invented and the needle itself carries no weight. Needles made of jewels are therefore, very satisfactory. These are much harder than steel and do not wear with the consequence that the very delicate recording surfaces are not injured. Modern methods of "hill-and-valley" recording permit moreover, a much deeper cut in the groove (for the wax is thicker at the bottom than it is in the wall of the groove itself) and this results in more accurate reproduction. Finally by the methods of suspension adopted "scratch" is almost eliminated.

CHAPTER 14

LIGHT

Although there were numerous ancient speculations regarding the properties of light, the first useful theory was put forward by Sir Isaac Newton (1642-1727). He suggested that light itself consists of minute particles projected into space from all light-giving bodies at the same great speed, and that the sensation we call light is due to the retina of the eye being excited by streams of these particles or corpuscles. In this corpuscular, or emission, theory of light, which was generally accepted until the 19th century, it was assumed that these particles travelled at great speed through transparent substances as well as through empty space. The crucial objection to the theory is that it supposes the speed of light, like that of sound, to increase with an increase in the density of the medium through which it passed. The erroneousness of this supposition was demonstrated experimentally by the French physicist Jean B. L. Foucault (1819-68) about the middle of the 19th century. In actual fact, light-waves travel less rapidly in denser media, and what Foucault showed was that light travels more slowly through water than through air.

Newton's theory was replaced by the "undulatory", or wave theory. This supposes that all space is filled with a medium capable of transmitting vibrations, and that a ray of light consists of a wave-motion in this medium. Such a medium must have qualities that resemble density and elasticity.

We know now that light-waves belong to that large group of radiations known as electro-magnetic waves—to which group also belong X-rays and wireless waves (Fig. 1). Electro-magnetic waves have an enormous range of wave-lengths and frequencies—the wave-lengths of some are measured in thousands of miles, whereas others are inconceivably short—as small as $\frac{1}{30}$ the diameter of an atom. The shortest electro-magnetic waves are the *gamma* rays of radium; they are beyond the X-rays and are similar to them, being very penetrating and producing harmful effects on the skin if it is exposed to them. At the other end of the scale are the slow oscillations beyond the Hertzian or wireless waves, having wave-lengths of from 20 to 2,000 miles.

Only $\frac{1}{60}$ of the scale of electro-magnetic waves is visible to the eye in the form of light, commencing with the violet and ending with the red. Waves of red light are about $\frac{1}{33,000}$ in. in length; those of violet light about $\frac{1}{64,000}$ in., which is about the limit of human visibility. The average length of light waves is about $\frac{1}{50,000}$ in.

INVISIBLE RAYS

Beyond the waves that give violet light are the ultra-violet rays, invisible to the human eye but which in some cases can be detected by the camera. These rays produce sunburn, and in excessive quantities do harm by causing inflammation. The shorter rays of this group—the far-ultra-violet—cause serious burns. At the other end of the scale beyond the red light-waves, are the infra-red waves. They also are invisible but produce the sensation of warmth, or "radiant heat" as it is called.

All these rays, from the gamma rays of radium to the slow oscillations beyond the Hertzian waves, are of electro-magnetic origin. They originate in

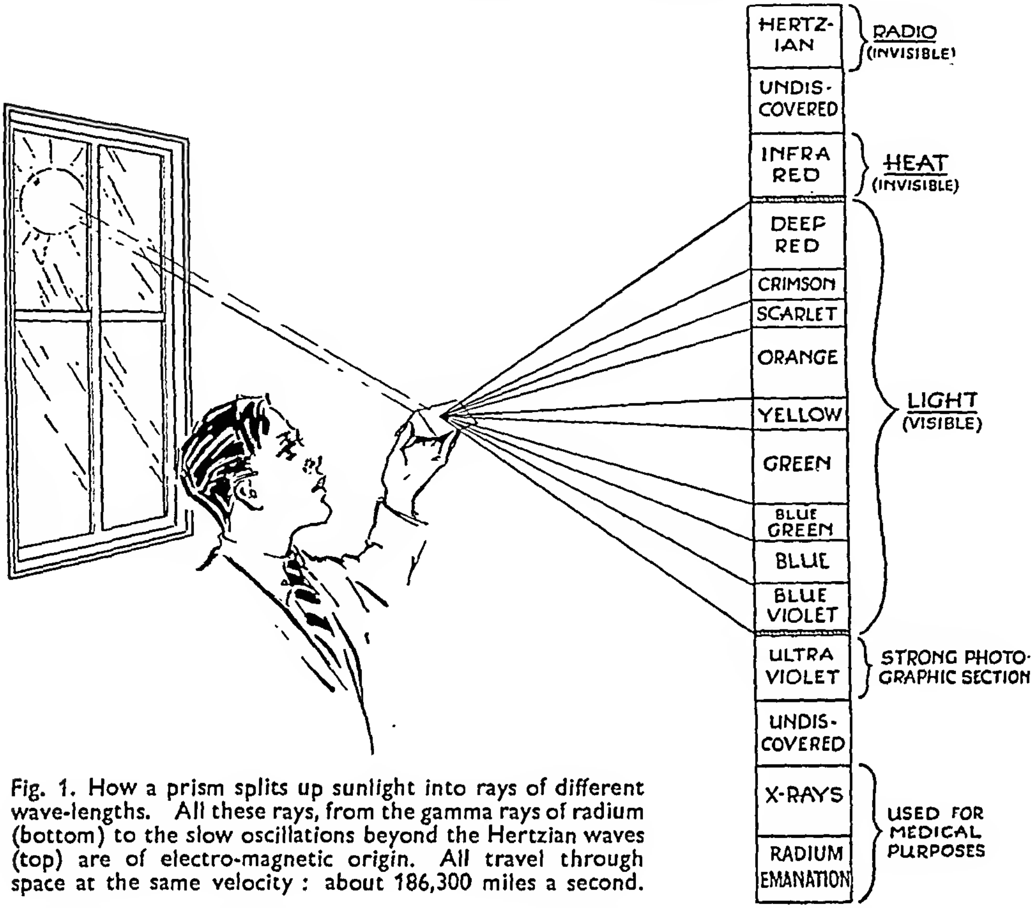


Fig. 1. How a prism splits up sunlight into rays of different wave-lengths. All these rays, from the gamma rays of radium (bottom) to the slow oscillations beyond the Hertzian waves (top) are of electro-magnetic origin. All travel through space at the same velocity : about 186,300 miles a second.

moving electric charges and apparently they all—whatever their wave-lengths—travel through space at the same velocity of about 186,300 miles a second. They differ from one another in an important way, however, for they travel in different sized *quanta* (singular, *quantum*), or "packets", as it were, and their different effects depend on the sizes of the "packets".

Max Planck, the German physicist who originated the quantum theory in the early years of the present century, has shown that, exactly as matter exists in atoms, so is radiant energy sent out in "atoms of energy", or units. The smallest particle of matter we know is an atom—we cannot have less than an atom of iron, for instance, and even the smallest piece of iron consists of a vast number of atoms. In electricity, a current is made up of units called electrons, and we cannot have an electric charge of less than an electron. Similarly, in radiant energy—such as light—we cannot have less than a unit, or "quantum" as it is scientifically called, of light. Any body that sends out any of these radiations or absorbs them must be concerned with a vast number of quanta, exactly as a piece of iron is concerned with a vast number of atoms.

One important point that we must remember is that a quantum is not a specific thing like an atom. It may consist of some hundreds of thousands of waves, depending on the number of vibrations made by the electric charge every second. The term quantum is applied to other things as well as to

light, and the "packet" in which the radiant energy of light is delivered is more specifically called a "photon".

The quantum theory is now generally accepted as explaining all the known mysteries about light. Before the introduction of this theory it was supposed that an unlimited amount of energy could be radiated by a hot body or luminous atom, but this idea is now believed to be incorrect. Radiant energy cannot be dealt with as though it is an infinitely divisible quantity.

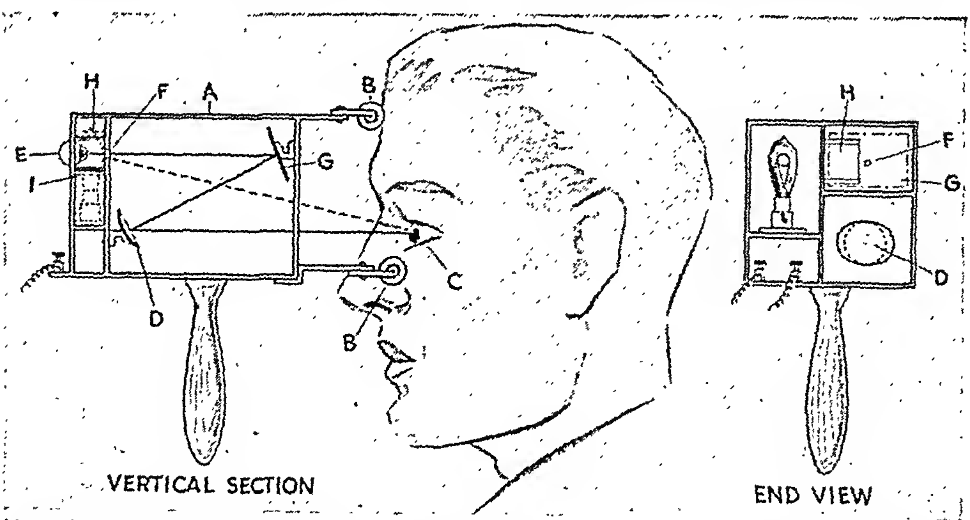
ELECTRO-MAGNETIC WAVES

An electro-magnetic wave differs considerably from the waves we have considered already. It does not resemble a wave on water, for this is a moving alteration in the shape of a surface. Nor does it resemble a sound wave, for this is a moving compression in air. An electro-magnetic wave is a combination of a moving electric and a moving magnetic field. The electric field rises and falls as the wave travels forward on a straight line at about 186,300 miles a second, and simultaneously the magnetic field rises and falls in unison with the electric field but at right angles to it.

Normally, light travels in a straight line and a familiar proof of this is afforded by a ray of light entering a room. It often happens that there are particles of dust in the atmosphere of the room. These "motes in the sunbeam" are lit up by the light-ray and thus show its path. This path is never curved. Again, when sunlight breaks through a gap in a cloud, it streams down in straight beams.

A single line of light is called a *ray*. Although it is not possible to isolate a single ray, it is useful to use the term *ray* in indicating the direction of light and for similar purposes. A collection of rays is called a *beam*, a narrow beam sometimes being referred to as a *pencil* of light. Beams may be parallel to or divergent from a point-source, or convergent on a point. This point—whether the beams diverge or converge—is called the *focus*.

Whereas sound will not travel through a vacuum, light travels in it quite easily. If it did not we should not



How the Thorner Ophthalmoscope for examining eyes works. (A) The case surrounding the ophthalmoscope, (B) spheres resting against patient's head, (C) eye of patient looking into (D) concave mirror, (E) the eye of observer looks through (F) aperture into (G) plane mirror, (H) Totally reflecting prism, (I) electric lamp for lighting patient's eye.

eceive light from the Sun or the stars. Chus whilst no sound can reach the Earth from beyond its atmosphere, ınd none penetrate beyond its atmos-)here into space, light travels through he whole of the universe, reaching us rom enormous distances in space.

We see, then, that electro-magnetic vaves are able to pass through a vacuum ınd do not depend on air for their ransmission. They are generally sup-)osed to be transmitted by the "ether", ı medium that is said to fill all "space" ncluding that between the molecules of natter. Exactly what this ether may)e is a mystery, for all attempts even o prove its existence have failed. Its existence was postulated by science to explain the passage of electro-magnetic vaves, for it was obvious that a medium of some kind was necessary to enable hese forces to be transmitted.

Before the second half of the 17th century it was supposed that light was an nstantaneous phenomenon; that is to say, that its speed was infinite and ncapable of measurement. That such s not the case, and that light travels at ı definite speed, was first demonstrated in a very interesting manner. We have already referred to the four principal satellites of the giant planet Jupiter, discovered by the immortal Galileo. As we have seen, in the course of their revolutions round Jupiter the satellites pass into the great shadow cast in space by this planet. When this occurs the satellites are eclipsed just as our Moon suffers eclipse when it passes into the shadow cast by the Earth in space. Watching the eclipse of one of Jupiter's satellites through the telescope we see the tiny moon quickly grow fainter and fainter and fainter as it passes farther into the shadow, until it finally disappears. When it has traversed the shadow it reappears, emerging as a faint point of light but quickly growing brighter until, when clear of the shadow, its full brilliance is restored.

About 1675, Ole Rœmer, a Danish astronomer, computed tables to show the times of future eclipse of Jupiter's satellites, such as may be found to-day in the *Nautical Almanac*. Having calculated what should occur, he observed the phenomena from time to time. He was astonished to find that although

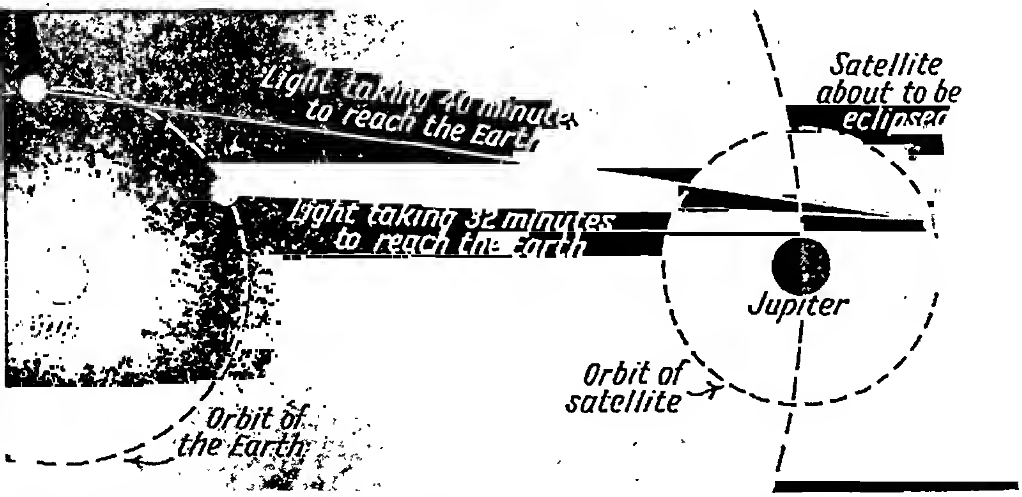
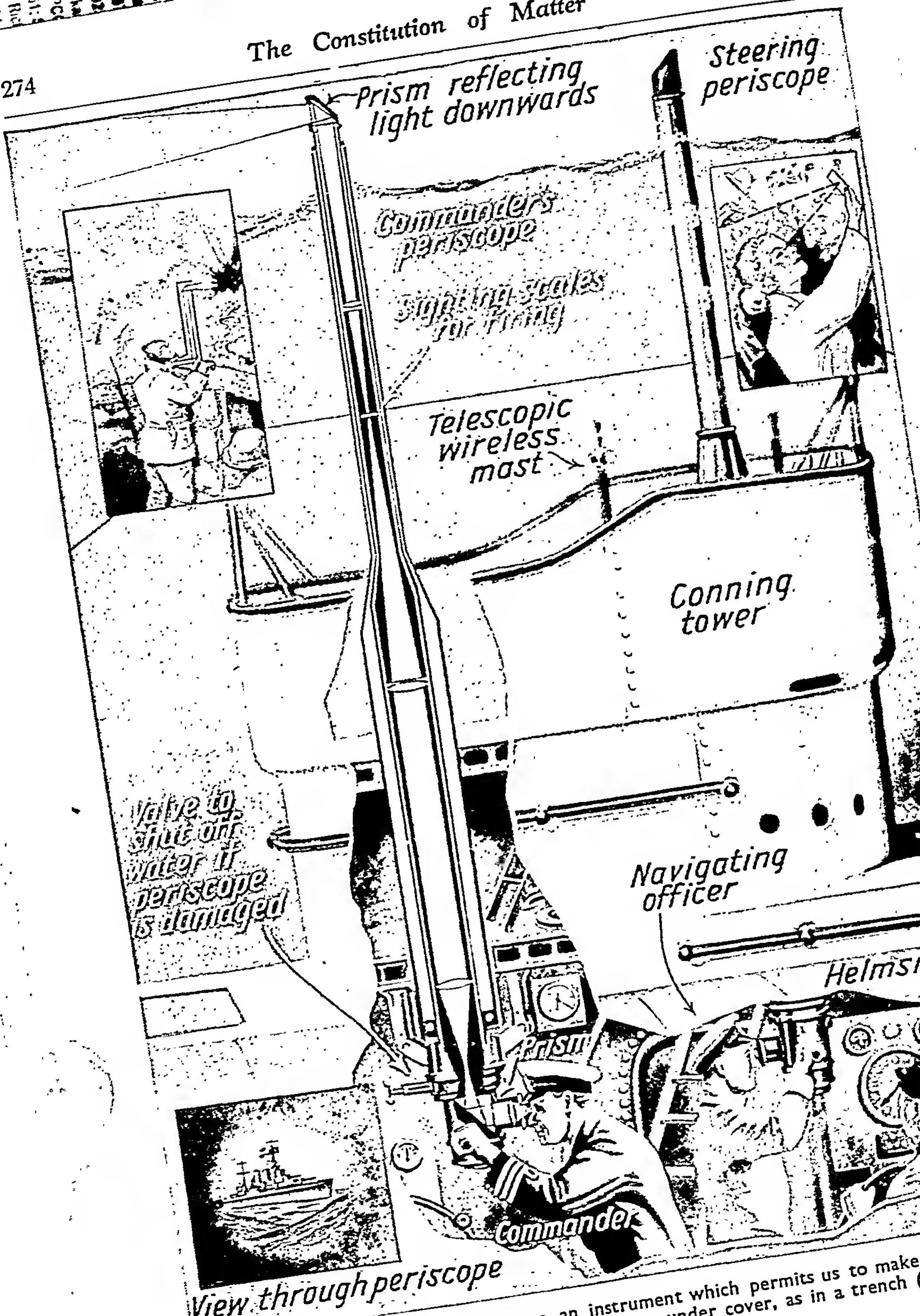


Fig. 2. How the velocity of light was determined by means of Jupiter's satellites. It was noticed that when the Earth was further away from Jupiter, the eclipses occurred later than predicted, and it was seen that this was due to the increased distance over which the light had to travel. The diagram is not drawn to scale in respect either of sizes or of distances.

Fig. 3. Measuring the velocity of light by Michelson's experiment (described on page 275).

at first the observed times of the eclipses agreed very closely with the computed figures, at the end of six months there were considerable discrepancies. Some of the observed times were as much as 16 min. 40 sec. behind the predicted times. At first no one could offer a satisfactory explanation of this. After a while, however, it was noticed that there appeared to be a certain regularity in the discrepancies. When the Earth was comparatively near to Jupiter, the eclipses occurred to time, but when the Earth was in a part of its orbit remote from Jupiter the discrepancies were very pronounced and the eclipses occurred late. At such times—every six months—the Earth was at a much greater distance from Jupiter than it had been six months earlier (Fig. 2). It thus became obvious that the apparent delay in the eclipses must be due to the fact



How the prism is used in the periscope, an instrument which permits us to make ... submerged, as in a submarine (bottom) or under cover, as in a trench (

that the light-rays from the satellites had to travel a much greater distance. This distance being known—as well as the time taken to cover it—a simple calculation was sufficient to show that light travels at about 186,000 miles a second, and this figure was subsequently confirmed by a series of ingenious experiments by various scientists.

MICHELSON'S EXPERIMENT

One of the most interesting of these (Fig. 3) was carried out by an American naval officer, Albert A. Michelson, between 1878 and 1882. He arranged for a beam of light to be brought to a focus and passed through a slit (A) on to a revolving mirror (B). From here it was reflected by stationary mirrors (C and D) to a concave mirror (E). From this point the beam was directed across country where, 22 miles distant, was another concave mirror (F) that reflected (G) the beam back to the first concave mirror (H). Here, by means of other mirrors (I and J), the beam was directed to a mirror (K5) on a revolving drum and then by another stationary mirror to a small telescope. Adjustments were made so that the observer saw the original slit as a bright line on a graduated scale marked in the eyepiece of the telescope. The revolving mirrors were driven at high speed by suitable gearing from an electric motor, and as they rotated they reflected the light as an intermittent beam along its 44 mile path, "out and home".

It is easy to understand that when the original beam from the mirror at B is returned to K, it will not find the individual mirrors in the same position as they were when the beam commenced its journey. As the mirrors have moved, the beam will be sent slightly to one side of the telescope slit, so that nothing will be seen. By speeding up the rotating mirrors, however, a point will be reached when the beam will impinge on mirror B1, travel the 44 miles, and find that in the meantime the mirror has made $\frac{1}{8}$ of a revolution allowing mirror 4 exactly to take the place of mirror 5. When the mirror-velocity has been so adjusted that this happens, the light will be seen in the telescope.

The experiment therefore consists in setting up the telescope so that the light can be seen, and causing the mirrors to revolve at such a speed that the light disappears and then appears again. Then is determined the speed at which the mirrors are revolving.

Let us suppose that the speed is 525 revolutions per second. Then $\frac{1}{8}$ of a revolution will take $\frac{1}{8 \times 525} = \frac{1}{4,200}$ second—the time required for the light to travel 44 miles. Thus, in one second the light would travel $4,200 \times 44$ miles $= 184,800$ miles a second. The figures we have taken are only approximate. The correct value is 186,325.

As in the case of many other figures in science in general and astronomy in particular, this enormous speed of light is quite beyond our conception. Compared with the speed of Sir Malcolm Campbell's record-breaking motor boat, which at 127 miles an hour covers 186 ft. per second, the velocity of light is about 5,250,000 times as great.

NATURAL SOURCES OF LIGHT

The natural sources of light—apparently inextinguishable and perpetual—are the Sun and the stars. They are to be distinguished, of course, from the planets and the Moon, for these only reflect the light of the Sun.

Artificial light is derived chiefly from various forms of combustion produced chemically by the application of heat in an intense form, or by an electric current. By such means light may be produced from solid, liquid, or gaseous

bodies. Solids give out light at lower temperatures than gases, and give off a greater light at any stated temperature. A flame, which is an incandescent gas, is brightest when it contains the largest proportion of solid particles in transit, derived from solid matter in course of combustion—in other words, the purer the gas, the less the light. It may be that it is because of this fact that the Sun gives out such intense heat and light, for the photosphere contains numerous metals in suspension—as, evidently, do also the stars—the incandescence of which radiates more effectively than would flames from pure gas.

MAKING LIGHT ARTIFICIALLY

To understand how light can be made artificially—whether by using candles, oil lamps, or electric lamps—we must refer back to our account of the structure of matter. As we have there learned, matter is made up of an infinite number of atoms and they in turn consist of electrons, or negative charges of electricity circulating around a positively charged nucleus.

Niels Bohr (born, 1885) has put forward the theory that the light negative electrons are grouped around the heavy nucleus according to the amount of their potential energy, and that there may be from one to 92 electrons so grouped. They are not simply grouped like the planets in their orbits round the Sun, but in concentric groups each of which contains a limited number of electrons. As will have been noticed in Fig. 8., page 200, the eleven electrons of an atom of sodium are represented as travelling in only three orbits, while the twenty electrons of an atom of calcium are shown as travelling in four, grouped thus: 2, 8, 8, 2.

If the electrons can overcome the attraction of the positive nucleus they can move from one group to another. They can overcome this attraction only with the assistance of extraneous influences, as when electrical energy is applied to gas in a tube such as in the neon tubes used in advertising signs. What happens there is that the atoms of gas absorb energy and this applied energy enables the electrons of one group to jump to another group that has less than its complete complement of electrons.

The number of groups to which the electron can jump is limited, and there must be a vacancy before the jump can take place. Probably what happens when electrical energy is applied is that some electrons are forced out of their groups, so causing vacant spaces into which other electrons can jump.

Similarly, if heat is applied, the heated atoms rush about and come into collision. The force of the collision generates energy that is absorbed by the electrons, and these then jump to vacant groups of greater energy. Other electrons jump back to groups of lower energy—there is a kind of "Family Coach, all change places!"—and when they do so a quantum of light is sent out. The wave-length—on which depends the colour—of this light is determined by the difference in the energy of the electron before and after its jump. Succeeding groups have an increasing potential energy, so that when an electron from a group having, say, three units of energy jumps to a new position, it may have five units of energy in its new position. When the electron jumps back, it loses potential energy and this energy appears as a unit or quantum of light.

GROUP ENERGY OF ELECTRONS

The important point here is that the energy of the groups of electrons has fixed values. Thus, if an electron jumps from a position of five units value

to one of three units value, the energy given out will be the difference between these values—i.e. two units. As the energy released at each jump is fixed, and as Planck has shown the relationship between the energy of a quantum and the frequency of light, it follows that the frequency of light is also fixed—in other words, at each jump of an electron, light of only one frequency will be emitted. As the electrons of the atom can only jump to a certain limited number of positions, there can be emitted only a limited number of light-frequencies.

Actually, although we do not know the "jumps", we do know the results—that sodium atoms emit characteristic yellow light; that neon gives a peculiar red light; that mercury vapour gives a brilliant blue-green, and so on. Of course, this is all theory, for as we have explained, no one can see an atom much less any of these jumping electrons. The important point is that the theory does seem to provide an explanation of the peculiar light that glowing gases produce.

Light is given out when a solid is made very hot, as we may learn by watching a blacksmith at his forge. We see the iron he is heating gradually get hotter and hotter as the fire and the bellows do their work. Before it actually begins to glow, the iron first becomes hot and then dull red. At this stage, when its temperature is about 500°C., it commences to give off the longest red light-waves as well as heat-waves. The red glow gradually changes to orange, then yellow, and if the temperature is high enough, to white, when a considerable amount of light of all wave-lengths is given off.

The great drawback in using heated solids for light-giving is that most of the energy is wasted as heat, because of the temperature at which we use them. The highest temperatures we can attain effectively are not high enough to give the most economical results. The tendency has always been to increase the effective temperatures—first the rush light, then the candle and the paraffin lamp.

After these came the gas-burner, the flame of which was later "hotted up" by the use of the Bunsen burner, the hotter flame being directed on to an incandescent mantle. This emitted a much greater proportion of light-rays than did the same amount of gas in the "bat's-wing" type of burner. The next improvement was the use of high-pressure gas which gave a 50 per cent. increase of light using the same mantle.

THE ELECTRIC LAMP

In the electric lamp an electric current heats a fine thread of conductive material until it glows to incandescence. The first lamps, with their carbon filaments, were severely limited by the fact that if the filaments were heated to over about 1,750°C., they disintegrated. They were followed by lamps with filaments made of metal that had a very high melting point—about 2,000°C. The metals used at first—osmium and tantalum—were rare and costly, but later a more suitable metal was found in tungsten. The difficulty was that it could be obtained only in the form of powder and could not be melted into bars for wire-drawing. Some years ago a method was found by which tungsten could be drawn into the necessary fine wire, and lamps with filaments of tungsten came into general use.

The filaments in the older lamps were placed in a vacuum, the air being exhausted from the bulb after they had been placed in position. By introducing an inert gas—such as argon—into the lamp, it was found that the filaments could be heated to higher

temperatures without any danger of their thinning and breaking. So, again, the gas-filled lamp enabled still another increase in temperature to be obtained.

Still searching after greater efficiency by using greater heat, lamp-makers made the filament into the form of a coil instead of a straight wire, and even more recently the coiled filament has been coiled on itself, forming the modern "coiled-coil" filament lamp (Fig. 4). The effect of this is to keep the filament from cooling as quickly as in the former lamps, so that it tends to use less current.

APPROXIMATE LAMP EFFICIENCIES

Despite all these advances, the present electric lamp leaves much to be desired. Here is a table of approximate lamp-efficiencies. It shows the percentage of the expended electrical energy that is actually converted into light:

	per cent.
Early carbon filament lamps (16 candle-power)	.. 0·56
Tungsten filament lamps ..	.. 1·28
Do. do. in vacuum (60 watt)	.. 1·32
Coiled filament, gas-filled ..	.. 1·55
Coiled-coil filament (60 watt)	.. 1·84

Low as these efficiencies are, they are better than those obtainable with gas-lighting, even taking the much greater economy shown by the incandescent gas mantle when compared with the earlier bat's-wing burners. With the low-pressure incandescent gas-mantle only 0·2 per cent of energy was converted into light, and with high-pressure gas, 0·3 per cent. On the other hand, we must bear in mind the fact that electrical energy for lighting costs anything from 5 to 15 times as much as its equivalent in heat-energy, but this—although of more practical importance to most of us—is the commercial aspect of the subject and not the strictly scientific.

As compared with the coiled-coil filament lamp, the glowing gas—such as is used in neon tubes used for advertising signs—is enormously more efficient. It would not be surprising to find that this form of lighting will in time replace the present filament lamps. Such lamps give about four times the amount of light for the same amount of electrical energy as the best coiled-coil lamp, 6·4 per cent. of energy being converted into light in the mercury hot-cathode lamp. Unfortunately, it is not yet possible to obtain a white light from them efficiently, but no doubt the researches that are being made in this direction will overcome this difficulty in the near future.

Sodium and mercury-vapour lamps are being increasingly used for the lighting of arterial roads, several ad-vantages being claimed for them. Fo instance, they are more serviceable i fog, and they do not cast shadow This type of lamp is familiar to mo people, and it will have been notic that in the light they cast objects take colours that they do not have when s in daylight or by ordinary artificial li This is because the lamps emit ligh only a few wave-lengths and it is in light that is a mixture of all kin wave-lengths—the nearest approa sunlight—that we can distinguish range of colours in their correct

LIGHT WITHOUT HEA

Although light is generally panied by heat, some bodies limited amount of light unacco by heat. This is the case wi phorus and those bodies i phosphorescent action is prese illuminating power of phosp due to its slow combustion o to the atmosphere. It the vapours that, although inv bright light, are seen in th

faint bluish glow. The leaves of some plants give off a phosphorescent glow on summer evenings, as also do some plants that grow in subterranean places. In the animal world, the glow-worn and the fire-fly are examples of a similar kind of light emission, as are also many kinds of shell-fish and marine animals.

MAGNIFIED SECTIONS OF THE DOUBLE-COILED FILAMENT OF THE MAZDA COILED COIL GASFILLED LAMP AND (BELOW) THE FILAMENT COIL AS USED IN THE ORDINARY MAZDA GASFILLED LAMP.

Courtesy of B.T.H. Co. Ltd.

Fig. 4. Filaments of ordinary coiled and coiled-coil lamps compared. Over 15 per cent. increased efficiency is gained with the latter. It cools more slowly and therefore tends to use less current.

Although there is no established connection between sound and light, the two phenomena have much in common, often exhibiting characteristics that are peculiarly alike. Both phenomena are due to regular periodic movements by wave-motions; but, whereas in sound the alteration in the frequency of the vibration alters the pitch of the note, in light it alters the colour. We have tone and harmony in musical sounds, and the same terms may be applied to colours. Combinations of musical harmonies can be produced, as can combinations of colour harmonies. Exactly as we say that two musical notes are not in harmony, so when two colours "clash" we say that the colours do not harmonise. Some people are totally incapable of appreciating beautiful music, and some are unable to match colours or to appreciate the harmony of certain blends of colours. Some people prefer a string quartette, others a brass band; some prefer pastel shades, others strong garish colours. Musicians and painters have much more in common than they generally realize.

We have spoken of musical and colour harmonies, and in this connection there has recently been invented an instrument for the production of sound and colour. This is the Kaleidakon that was demonstrated at Earl's Court in April 1939. A luminous kaleidoscopic tower, 86 ft. in height filled the grand arena with rainbow-lighted melody. Rising from the bank of a shimmering lake, 6,000 ft. square, it flung its own reflection across the iredescent water. Seated at the console of this instrument the organist manipulated the keys and stops that control its melodies, an expert accompanist controlling the light and colour combinations. The Kaleidakon is a work of art and ingenuity to produce which experts in light, sound, and electricity have devoted their skill and their knowledge. It shows in a striking manner how colour and musical harmonies can be combined with effects pleasing to both eye and ear (see illustration on page 310).

OPACITY AND TRANSPARENCY

Whilst a few bodies freely allow light-waves to pass, others interrupt their progress to a lesser or greater degree—most often completely. We describe bodies as being transparent or diaphanous, translucent, and opaque—as, for example, clear glass, frosted glass, and wood. In actual fact there is no such thing as perfect transparency, however, for all objects reflect some proportion of light, as we shall explain later.

As light-waves move in straight lines, an opaque object on which light falls intercepts the light-rays, casting a shadow that is similar in outline to a section of the body producing it.

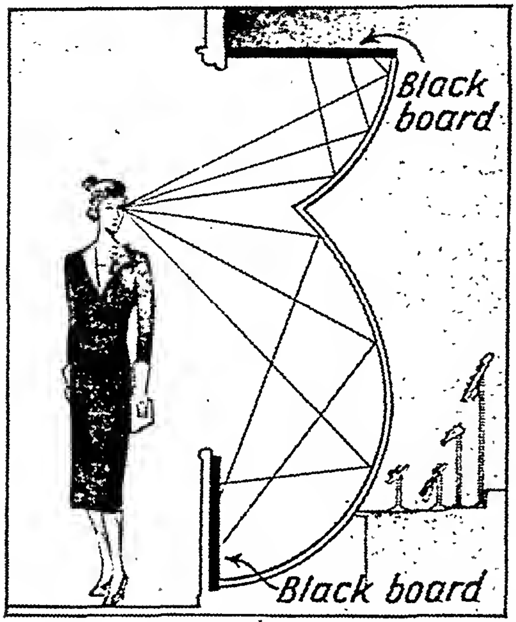


Fig. 5. The newest shop-windows are curved inwards to ensure that rays reflected from their surfaces to the eyes of shoppers come only from the black boards above and below.

When light strikes an object, four things may happen. One portion of the ray may be reflected in a diffuse manner, and it is by this diffusive reflection that we are able to see objects that are not self-luminous. Another portion of the ray may be thrown back or directly reflected. A third part may be absorbed by the object and its energy transformed into heat. Finally a fourth portion of the ray may pass through the object—as, for instance, through a pane of glass or a sheet of water—when its direction of travel is changed and it is said to be refracted.

All substances reflect some proportion of light. In looking through a window we do not get the full light-value of the scene beyond, for the glass reflects a proportion of the light that is in proportion to its thickness. To obviate the nuisance of reflection, which prevents customers from obtaining a full view of the goods displayed, some shop windows are constructed with concave shaped glass. Fig. 5 explains how this arrangement eliminates the unwanted reflections, and enables the goods in the window to be displayed as though there were no glass between them and the customer.

As no substance is perfectly transparent, so there is no substance that possesses the property of perfect reflection. A sheet of gold leaf appears to be a perfect reflector, but if held up to a strong light it will be seen that it permits bluish rays to pass through.

REFLECTION AND ABSORBTION

In the theory of wave-motions it is one of the primary laws that the angle of incidence and the angle of reflection are always equal one to another. It is because of this that images are formed in a looking-glass. As we always see objects in the direction in which the ray of light arrives at the eye, the image appears to us to be as much behind the surface of the glass as the object is before it.

Reflectors have many uses, as in a motorcar headlamp in which a concave surface so reflects light that all the rays are converged to a parallel beam. Reflectors are also used in numerous instruments, particularly lanterns, ciné projectors, etc., and in astronomical telescopes, as will be described more fully later.

Reflection does not alter the ray of light—it merely alters its direction. For this reason a reflected ray will behave exactly as the original ray when it falls on any object. A portion of it is scattered by the object on which it falls, and when the scattered light falls on other bodies it is again reflected and dispersed, making them visible but in a somewhat less degree because of the partial absorption that has already been mentioned.

All bodies absorb a certain amount

of light, the amount depending on the substance on which the light falls. If a ray of light, admitted through a hole in the shutter of a dark room, falls on a sheet of white paper the whole room will be well lighted, but should it fall on black velvet the room will remain dark, for then the whole of the light will be absorbed by the velvet. The atmosphere has remarkable absorbent properties due to which the Sun's light is diffused so that objects are visible when sunlight does not directly fall on them. Without this property objects shaded from the Sun would be invisible. If the Earth were not enveloped in a dense atmosphere the Sun would appear as a fiery orb against a dark sky.

There is a recently developed material, known as Polaroid, that has some remarkable properties. In appearance Polaroid is a thin transparent film that looks and feels like celluloid, but is somewhat darker. A sheet of Polaroid is actually an assemblage of needle-like crystals, several thousand billion of which are embedded in a square inch of the material. All these crystals lie parallel and they are so small and so closely packed together that the actual structure of the sheet cannot be seen unless magnified over 1,000 times by the microscope under polarised light.

WHAT IS POLARISATION?

A sheet of this material "combs out" the light that passes through, arranging the rays so that they are all in parallel planes. The effect of this, called *polarisation*, is similar to that of random waves moving along a rope, tied at one end, and moved about in all directions at the other. If the rope passes through a gap in a fence, all the vibrations will not get through but those that do will all be parallel with the gap between the palings. In practice, the light-

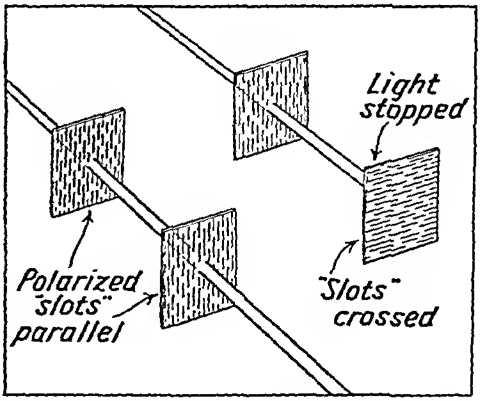


Fig. 6. (Left) Light passing through two sheets of Polaroid, arranged so that the "slots" are parallel. (Right) With slots of second sheet at right angles the light beam is completely cut off.

beam's "fence" is Polaroid, and after it has passed through it the vibrations are all arranged in the same plane. It is this arrangement of the vibrations in one plane that makes them controllable, for when a second "fence" of Polaroid is placed in the path of light, with its holes at right angles to that of the first sheet, the vibrations cannot pass and no light gets through (Fig. 6).

To the eye, light that has passed through Polaroid looks like ordinary light. Nevertheless, it can be made to do a thousand things that ordinary light cannot be made to do. It can be used to detect strains, for when glass and other transparent materials are subjected to stress they develop quasi-crystalline characteristics corresponding in degree to the amount of strain. When viewed between crossed sheets of Polaroid, the strained areas appear in white or colour against the black of the rest of the field. If strains exist in a bottle, for instance, the areas where they occur show up clearly as shown in the photograph in Fig. 7.

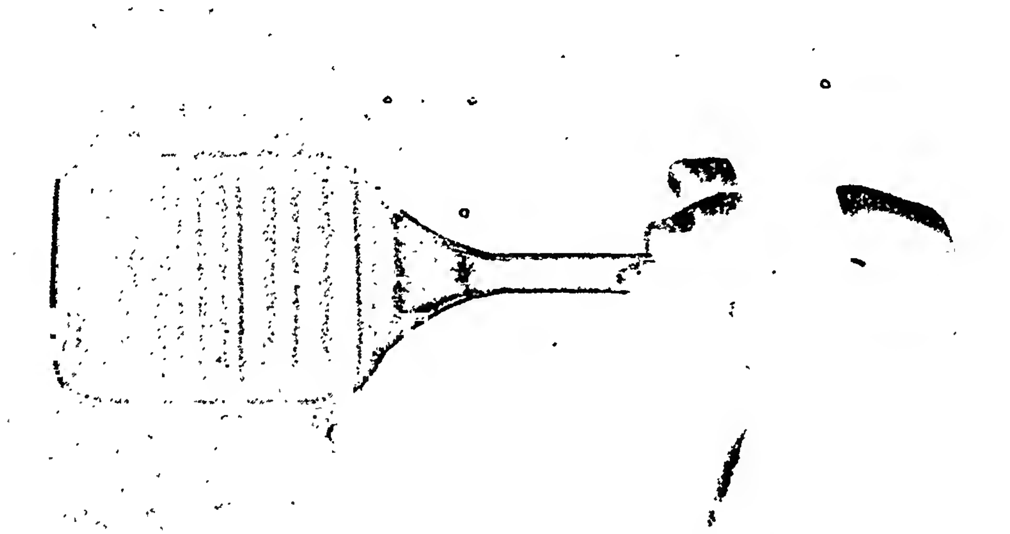
There are many other industrial uses of this new material. Manufacturers can detect faulty processing; users of glassware can determine its quality before they

buy it. By applying to a model forces that correspond to the forces that will occur in service, an engineer can discover how efficiently the members he is designing will carry the loads they will meet in service. Strains appear as a map of light and dark bands in the model, and from this map the strain at every point can be calculated so that the behaviour of the full-size parts in service can be predicted.

Blinding headlights are held to be responsible for the loss of tens of thousands of lives every year. When the form of Polaroid designed for automobile headlights is released, most of these lives will be saved, for it will be possible to eliminate headlight-glare. Each car is fitted with a windscreen of Polaroid, with its "slots" arranged at an angle of 45° to the road. The headlights are fitted with Polaroid lenses with their slots at exactly the same angle. The combed light goes out from the headlights, strikes the road and is reflected back through the Polaroid windscreen to the driver, who gets the benefit of his own headlights, because windscreen and headlight slots are parallel. But when two cars, equipped in this way, meet each other on the road, neither driver sees the direct light of the approaching headlights. Parallel when the cars are headed the same way, the slanted optical slots of the Polaroid are now crossed at right angles because the cars are facing each other. Light from the approaching headlights cannot get through the windscreens and all glare is eliminated (Figs. 8 and 9).

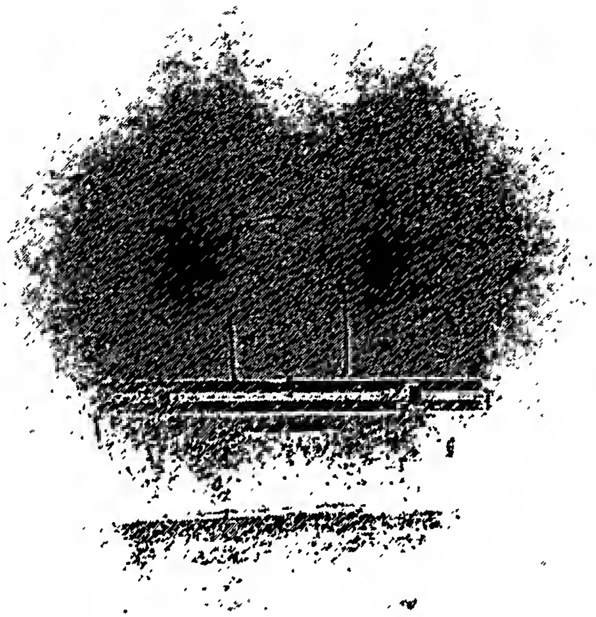
Approaching headlights are not invisible, but appear as faint discs, dim but clearly discernible. Details of the road, pedestrians and driving landmarks, are as clearly visible as if no other car were approaching. Experiments are in progress on other applications of this principle; as to photometers, light valves, adjustable sun-glasses, windows for privacy and for variable-density.

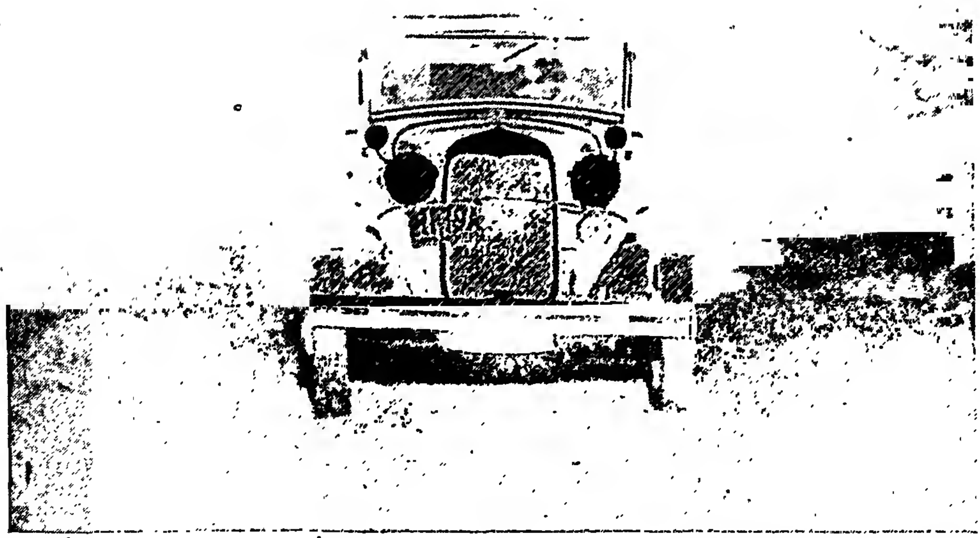
With a single Polaroid screen over his lens, the photographer can photograph obliquely through glass and water, reducing unwanted surface reflections and glare (Figs. 10 and 11). By rotating the screen to the correct angle



Courtesy of Polaroid Products, Ltd.

Fig. 7. A bottle showing concentric bands of internal strain when inspected between crossed Polaroid discs. Because of its capacity for showing up flaws, Polaroid is valuable to manufacturers.





Courtesy of Poloroid Products, Ltd.

Figs. 8 & 9. How Polaroid will help the motorist to see properly at night, and thus reduce accidents caused by glaring headlights. (Top) Car with ordinary headlights. (Bottom) Polaroid headlights and observed through a Polaroid windscreen. Polaroid completely eliminates the blinding effects of headlights that are the motorist's terror.

Courtesy of Polaroid Products, Ltd.

Figs. 10 and 11. Illustrating the use of Polaroid in photography. The top picture was taken with an ordinary lens. Its blurredness is due to the "glare" that arises when strong light falls on shiny paper. The camera with which the lower picture was taken, had a single Polaroid screen over its lens, and this made it possible for a very much clearer photograph to be obtained.

he can subdue bright oblique reflections that he finds objectionable; and he can darken a blue sky when photographing in a direction at right angles to the Sun's rays.

One of the most interesting developments, however, is in connection with three-dimensional ciné pictures. Let us examine the principle underlying the development of three-dimensional pictures. In life, the view seen by the left eye is always slightly different in the cinema. In three-dimensional movies, the camera looks at the scene exactly as a pair of human eyes would look at it, and takes two simultaneous views of it. In projection, the two views are shown on the same screen, one over the other. Each image is projected through Polaroid, set in such a way that the left-eye image reaches the screen with its light-vibrations vertical, the right-eye image with vibrations horizontal (Fig. 12). The audience,

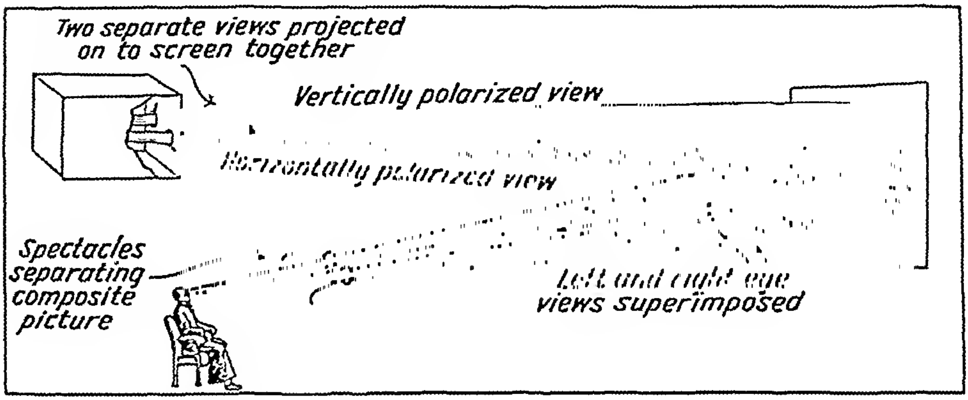


Fig. 12. Stereoscopic picture-projection. Two views are taken by the cine camera from two view-points. These views are projected simultaneously on to the same screen, one as a vertical and the other as a horizontal view. Observers equipped with Polaroid spectacles are enabled to "unscramble" the composite pictures, being thus endowed with stereoscopic vision.

from that seen by the right, as we saw in considering parallax and as was shown in Fig. 23, page 24. If two photographic images of such views are projected one over the other, the right-eye view polarised in one plane and the left eye view polarised in a plane at right angles to the other, observers will see the views as solid three-dimensional forms if they look through Polaroid spectacles with the "slots" of the right and left lenses arranged to correspond.

The ability to reproduce on the screen what the human eye picks up during every minute of normal life—the third dimension or the impression of depth, roundness, and realness of the things looked at—has hitherto been lacking supplied with Polaroid glasses with the lenses set at corresponding angles, sees one image with the left eye and the other with the right. Each eye sees one picture and one picture only. The screen itself seems to disappear. The observer feels that he is looking through a great open window at real actors and actresses engaged in real action taking place then and there.

When any object is illuminated it either reflects or absorbs the whole of the rays of which light is composed, or it reflects some and absorbs the remainder. When the whole of the rays are reflected the object appears to be white; if all are absorbed it appears to be black. If part of the rays are absorbed and part reflected the object

Fig. 13. A stick in a glass of water appears to be sharply bent, due to refraction.

appears to be the colour of those rays that are reflected. For example, the body of a pillar box appears red because all except the red rays are absorbed. When paint that absorbs all the rays is applied to the lettering on the pillar-box the letters appear black. The "time of collection" plate, being made of material that reflects all the rays, appears white. All variations of colour are produced by the reflection of certain rays in combination. The surface of a painted garden seat absorbs most of the red and blue rays, but reflects those of green so that the seat appears to be of a green colour.

FAMOUS QUAKER GOES RED

Some people are incapable of distinguishing colours, due to a curious defect of vision called "colour-blindness". Most people—more particularly men—suffer from a mild form of colour blindness, and in bad cases this may amount to total colour-blindness when the person is unable to distinguish any colours other than white and black. Others are unable to distinguish between red, blue, and yellow; or between these and green, purple, orange, and brown. In the milder cases there is inability to distinguish between the more delicate shades and hues, as in grays and neutral tints.

One of the most interesting cases of total colour-blindness was John Dalton, whose name we have already mentioned as the originator of the atomic theory. Although he belonged to the Society of Friends, the members of which dress very quietly, Dalton selected and wore a scarlet coat, being utterly unconscious of the fact that it was not of the approved sober hue! From this occurrence this peculiar defect of vision was at one time known as "Daltonism".

From the view-point of public safety, the inability to distinguish between red and green is a serious matter, more particularly now that so many crossings are controlled by "traffic lights". Severe tests for colour-vision are imposed on would-be locomotive-drivers, and it may be that in the future similar tests will be applied to motor car drivers before they are granted a licence to drive.

Colouring matter can be extracted from many substances and used as dye-stuffs. Such colouring matters as are capable of fixing themselves to fabrics without the intervention of any other substance are called "direct colours". Those colouring matters that require a substance to "fix" them are called "mordant colours", a mordant being a substance that has a chemical affinity for colouring matter. Until 1856 dyes were obtained only from animal or vegetable substances, but in that year W. H. Perkin obtained aniline mauve from coal-tar. Since that time the range of colours and their vividness and permanence has so increased that natural dyes have been superseded almost entirely.

The colouring of materials, or dyeing,

is a very ancient art and has been practised from the earliest times. Silk, wool, cotton, leather and textile materials are dyed and made to look more attractive, so giving variety to our daily life. To be satisfactory, any such colours must not be removable by washing or rubbing, or by light, the ideal process causing a permanent union between the material and the colouring matter. What actually happens in dyeing is one of the mysteries of science. The union seems to be a chemical one, however, although the physical characters of the material probably assist in the process.

REFRACTION OF LIGHT

When light travels through air it moves in a straight line only as long as the air remains throughout of the same density. Should the ray pass from air into water, or vice versa, where the medium is of a different density, it is refracted, or bent, out of its original course. We have a familiar illustration of refraction in a stick that is held at an angle half-in and half-out of water, when it appears to be bent at the point at which it enters the water (Fig. 13). The same thing is seen with a straw or a spoon in a glass of water. The degree of refraction depends on the particular media, each of which has its own degree, some refracting to a greater extent than others. As a general rule these refractive powers are in proportion to the densities of the substances. Water has a greater refractive power than air, and its power is increased when different salts are added. Glass has a greater refractive power than water, the power varying with the different optical properties of the glass.

The direction of a ray of refracted light depends not only on the surface by which it enters the medium but also on the surface at the point of exit. By suitably adjusting the surfaces of refracting media, the rays of light may be deflected as desired. Thus the original deflection of a ray may be doubled at the point of emergence if so required. This is of the greatest importance, for it enables prisms to be worked and arranged in different ways to give the many varying effects required in optics.

Refraction gives rise to many interesting phenomena. Often it will be noticed that stones seen at the bottom of a shallow pool appear to be displaced and nearer to the opposite bank than they really are, owing to refraction. Although the light from the stones has travelled directly to our eye it has been bent in passing from one medium (the water) to another (the air).

We have an instance of the truth of the old saying that "things are not always what they seem" when the Sun is setting, for when the last tip seems about to disappear, actually the Sun is well below the horizon (Fig. 14). This, too,

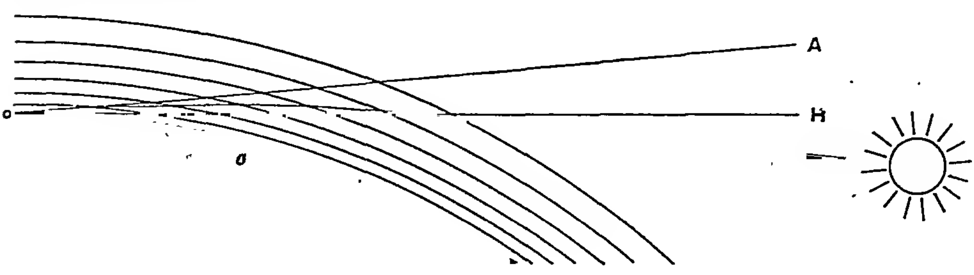


Fig. 14. When the setting Sun is visible just above the horizon, it is actually below it, but the light-refracting powers of the atmosphere make it appear above it. In the figure, H is the horizon-level and A the apparent position of the Sun, which is actually below the horizon.

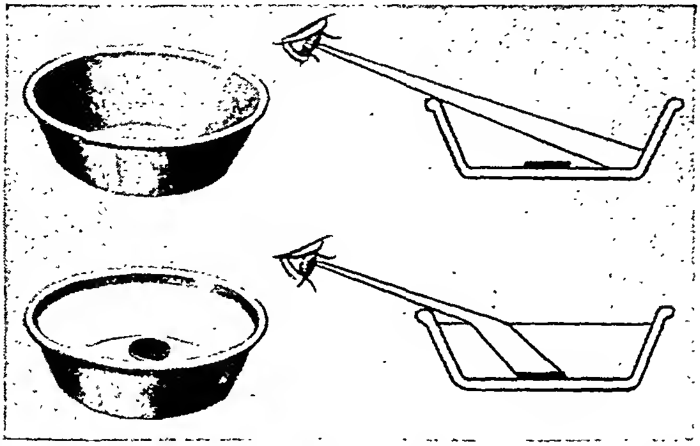


Fig. 15. Water refracts light. The upper bowl is empty and since the line of vision is straight, the coin is invisible ; the lower contains water and the line of vision is bent downwards. The coin is therefore seen without any difficulty.

is due to refraction and it affects not only the Sun—at sunrise as well as sunset—but all the heavenly bodies also. Thus, the Sun, Moon, and stars appear to be above the horizon at their rising and setting, when actually they are below it. The phenomenon may be illustrated by placing a coin in a basin and walking away from it until a place is reached where the coin just cannot be seen over the edge of the basin. If a friend now fills the basin with water, the coin will immediately become visible to the observer. The rays of light from the coin are of course, refracted by the surface of the water (Fig. 15).

PHENOMENA OF "LOOMING"

There is also the allied phenomenon, in connection with terrestrial objects, known as "looming". The rays of light from objects below the horizon are so refracted that distant objects—ships or villages, for example—normally invisible because they are below the horizon seem to be raised above it. This is probably caused by the atmosphere being in contact with water or land that is at a lower temperature.

In the Polar Seas, ships actually below the horizon have been seen as if raised well above it. William Scoresby, the Arctic explorer, told how, when cruising off the coast of Greenland, he saw every detail of the ship *Fame*, although it was actually 17 miles below the horizon. On another occasion when H.M.S. *Archer* was cruising in the Baltic, the whole of the British fleet was seen as though suspended in the sky upside-down, when at the time it was 30 miles distant. At Mauritius a pilot once saw a vessel when it was actually 200 miles from him, and on another occasion the Bombay packet was sighted from Aden when 200 miles off.

From the sea's edge at Zoppot, a small port near Danzig, the inhabitants sometimes see the peninsula of Hela with its village and lighthouse. This place is 25 miles from Zoppot and is therefore below the horizon from there. The good people of Zoppot do not regard this as an optical illusion but as evidence either of their keen sight or of a very clear day.

One of the best examples of this class of phenomena is the "*fata Morgana*" that is occasionally seen across the Strait of Messina from the coast of Calabria. The spectator apparently sees loftly castles, towers and palaces; or villages and trees, with cattle grazing in wide plains. The explanation lies in the "looming" of parts of the town of Messina, which are thus rendered visible to the inhabitants across the strait.

At various times "looming" has been reported in England and especially on the south coast. From Hastings, the French coast of Picardy, 45 miles distant, has been clearly seen extending from Calais and Boulogne to as far south as Dieppe. From Dover, the cathedral

and Napoleon Column at Boulogne have been seen—once with a telescope a train was seen to leave Boulogne and travel towards Calais. The churches and buildings of Hull and shipping on the Humber, have been seen from Bridlington, 32 miles distant, and on one occasion the town of Grimsby was clearly seen although 40 miles distant.

Another class of optical phenomena of the same order is also due to refraction and is explainable by the laws of optics. When the lower strata of the atmosphere become heated by contact with the land, they expand so that some of the rays of light from a distant object are refracted whilst other rays that do not pass through the heated strata travel in the normal way. To the observer the distant object is then seen as though it were in two positions. Once, on the savannas, or plains of South America, part of a herd of oxen feeding about a mile away appeared to be suspended in mid-air, the remaining animals being seen in their normal position. Sometimes the effect is that the image is seen in duplicate, one image above the actual object, which is of course invisible, and the other above the first but inverted.

Variations in the temperature of the atmosphere cause differences in its density and consequently its refractive powers also vary. Extreme changes due to local heat or cold may cause extraordinary optical phenomena such as

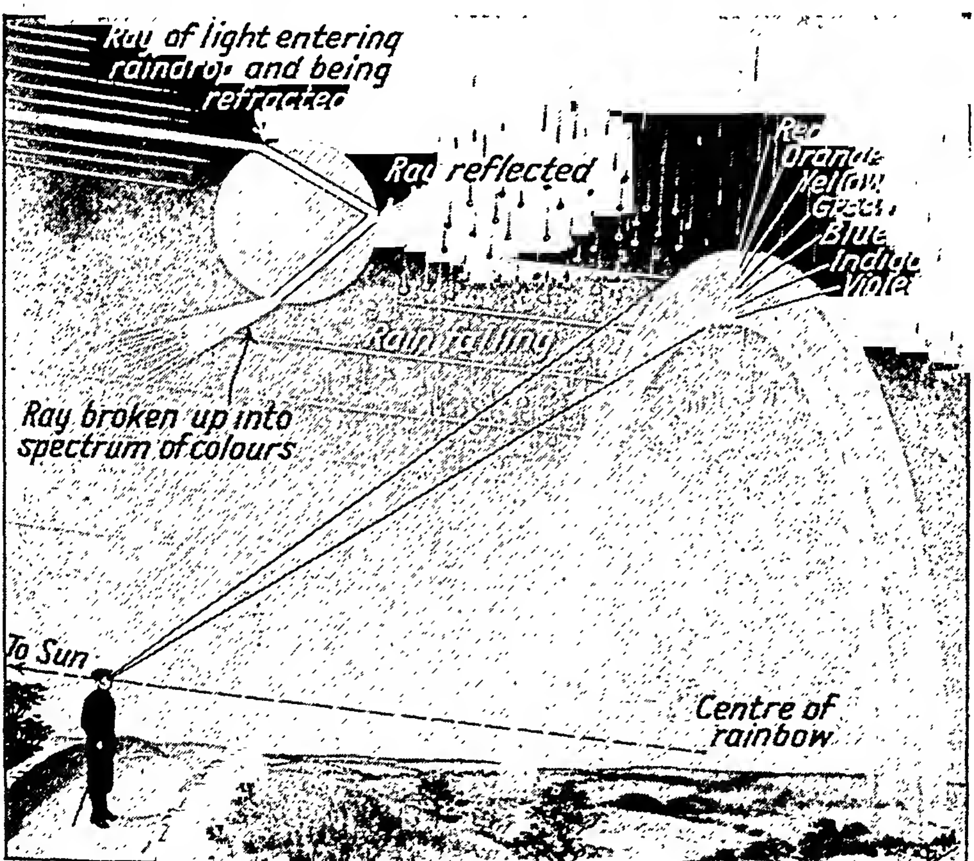


Fig. 16. The mysteries of the rainbow simply explained. (See page 290 for full explanation.)

mirages (French: *se mirer, to be reflected*) seen in deserts, in the polar regions, and more rarely even in Britain. Often desert mirages are so realistic that even experienced travellers have been deceived, imagining lakes or water where none exists. Such deceptive mirages have been known from the earliest times and are mentioned in the Koran.

SOME EFFECTS OF REFRACTION

It is also due to refraction that the Sun sometimes appears oval, or curiously misshapen, when low down in the sky. This is explained in the following way. At the point immediately overhead—the zenith—there is no refraction, but it increases towards the horizon, where it is greatest, because the more obliquely light enters the atmosphere, the greater is the refraction. Consequently, the rays from the lower parts of the Sun are refracted to a greater extent than those from the upper part, causing it to appear oval at sunrise and sunset.

A rainbow, which is also due to refraction, occurs when the Sun's rays, shining on very small drops of water in the atmosphere, are bent and split up into their primary colours on passing through the drops (Fig. 16). Here the water acts exactly as a prism splits up a ray of light to form a spectrum, as we shall shortly describe, the raindrop representing the prism and the background the screen on which the spectrum is projected. Certain conditions are necessary for the production of a rainbow. The Sun's rays must impinge on the falling rain; the Sun's altitude must be less than 45°, and the spectator must be interposed. The rainbow always appears in the region of the sky opposite to the Sun and occurs when the Sun is shining and rain falling at the same time, although it is not necessary for the rain to be falling in the same place as where the observer is standing. As a line from the Sun to the centre of the arch will pass through the head of the spectator, it follows that each person will see his own rainbow.

Sometimes a double rainbow is seen—a perfect rainbow that presents the appearance of two concentric arches. The brightest, the "primary", is always red on its outer edge and violet on its inner edge, the other colours being arranged in their correct order between, as in the spectrum. Outside the primary may sometimes be seen the secondary bow with colours in the reverse order, the red being on its inner and violet on its outer edge. In such a case the primary bow subtends an angle of 41° at the observer's eye and the secondary bow an angle of 52°.

As the Moon reflects sunlight it follows that if the conditions are suitable there can be a rainbow at night. Lunar rainbows, as these phenomena are called, are sometimes seen, and they do not differ in the theory of their formation from solar rainbows. They are less bright, but the full range of colours from red to indigo can be seen when conditions are favourable.

INTERFERENCE IN WAVE MOTION

If we throw two stones into a pond, we produce two separate series of waves. It may occur that the crests of the waves of one series will unite with the crests of the other series, producing a wave that has an amplitude equal to the sum of the component amplitudes. On the other hand, it may be that the crests of one series meet the troughs of the other, when the resultant amplitude is the difference between the component amplitudes. If these should be equal, one "cancels the other out", as it were, and there is no disturbance of the level of the water on the pond. This phenomenon is known as "interference".

In the case of light-waves, it is possible

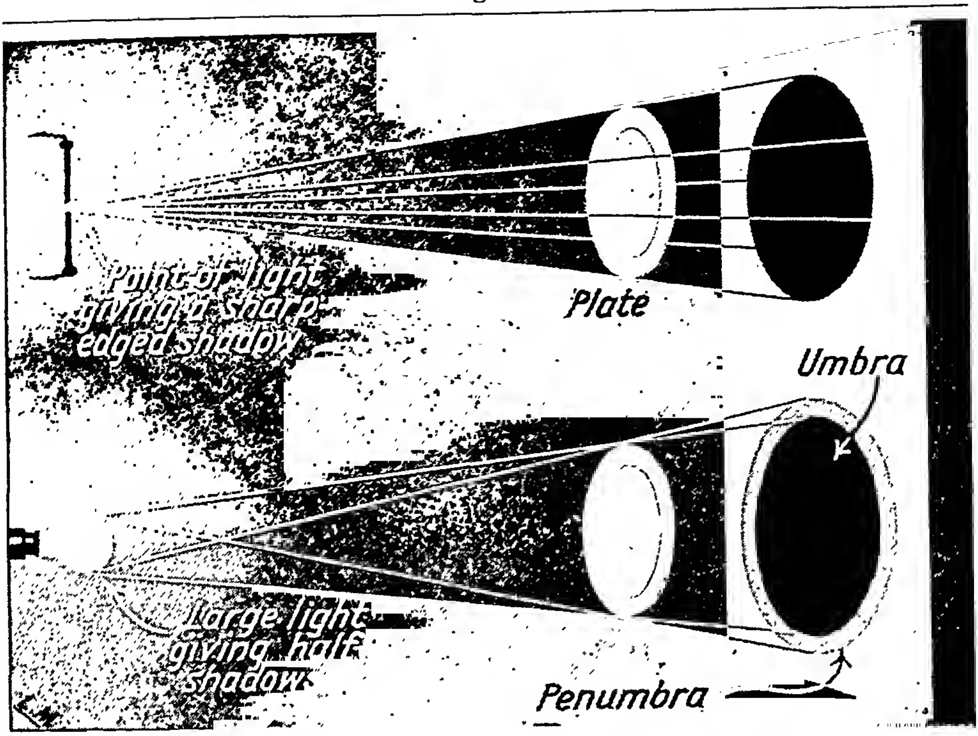


Fig. 17. Light coming from a small point (top) causes a sharp shadow, or umbra, but a larger light-source gives, besides an umbra, a fringe of lighter shadow known as a penumbra.

to produce a combination of rays that will give either increased or diminished brightness, or even complete darkness. Interference would have proved the falseness of the corpuscular theory of light, for two streams of light could not merge with one another in the way we have described if light consisted of particles of matter. The particles could only mingle with one another, but could not cancel out each other.

We know that we can hear a sound even when the source of the sound and our ears are not in an uninterrupted straight line. In other words, sound waves can turn corners. But such is not the case with light, and we are led to wonder why this is the case, seeing that light, like sound, is propagated in waves. The fact that light does not bend round a corner was held to be one of the chief objections to the undulatory (wave) theory of light, when it was first brought forward.

The explanation lies in the fact that in the case of sound the wave-lengths are almost comparable with the dimensions of ordinary objects—middle C on the piano, for instance, produces waves about 4ft 6in. in length. In the case of light, however, the wave-lengths are infinitely smaller. For example, the length of the wave that produces the yellow light of sodium is over 2,000,000 times smaller than the sound-wave of middle C. Most objects that are placed in the path of a ray of light are of much greater dimensions than the length of a light-wave. Light could be made to "bend round a corner" if the light-ray were passed round some object that is comparable in size with the wave-length of light.

To a certain extent this can be

demonstrated by allowing a ray of light to enter a darkened room alternately through two metal plates, the beam being directed on to a sheet of cardboard standing parallel with the metal plate. If a wide slit is cut in one of these plates it will be seen that the resulting image on the cardboard is sharp and clear at its edges. In the second metal plate an extremely narrow slit is cut, say with a sharp penknife or a razor-blade. The resulting image in the cardboard will be seen to be bordered by a series of alternately dark and bright bands that extend into the surrounding area. The fact that with the narrower slit the surrounding area does not remain entirely unilluminated shows that to a certain extent the light has bent round the edge of the slit. This bending effect is known as "diffraction".

UMBRA AND PENUMBRA

As everyone knows, opaque objects cast shadows owing to their obstructing the rays of light. The shadow is invariably the shape of the obstructing body and if the source of light is a point the shadow is of uniform depth and has a sharp outline. When the source of light is not a point—as in the case of the Sun, for instance—the shadow is not of uniform depth (Fig. 17). The inner or deeper shadow is called the *umbra*, and the outer or lighter shadow the *penumbra*. At the time of a lunar eclipse the Moon first enters the penumbra, or lighter shadow, cast by the Earth, later having passed through this, it enters the umbra, or shadow proper.

Light may be produced by chemical action, and conversely chemical changes may be produced by light. This is commonly noticed in the fading of the colours with which many cloths are dyed, particularly when subjected to a long exposure in strong sunlight.

Light is of great importance to nearly all living organisms, and particularly so to plant life. Here, chemical changes are produced by the influence of sunlight, chiefly in the building up of starch from carbon-dioxide and water in the leaves of plants. If deprived of light, plants grow white and contain an excess of saccharine, for they depend on the Sun's rays for the variety, beauty, and intensity of their colouring. To Man also sunlight is necessary for life, health, and strength, the health-giving properties of certain rays in the spectrum near to those of light being evidenced by the service they render to medicine.

Light is capable of producing powerful chemical action resulting in definite changes that may be turned to good account. One of the most striking of these is the action of light on salts of silver by which the salts are decomposed in varying degree according to the intensity of the light acting on them. This is the basis of photography (Greek: *phos* "light" and *grapho* "write"). The photographer relies on the fact that some of the compounds of silver—and more particularly its compounds with chlorine, bromine, and iodine—are extremely sensitive to light.

THE MODERN CAMERA

Before describing how a photograph is obtained let us for a moment consider the mechanical and optical side.

The modern camera is a development of the camera obscura, the principle of which appears to have been known to Euclid about 300 B.C., but which was not given serious attention until the 13th century. It consists of a darkened chamber into which light may enter only through a small aperture. The early experimenters discovered that if a chamber was completely shut off from outside light, with the exception of a very small hole in one of the walls, a

perfect image of the outside scene was thrown on the wall opposite the small hole. The image was in natural colours but it was upside-down, the reason for which is made clear by the smaller drawing in Fig. 18. Light reflected from the man A-B enters the dark box through a pinhole at C and is thrown on the back of the box at D-E. If we looked from the top of the man's head from the point A through the pinhole insert a photographic film (Fig. 18). It is quite practical, in fact, to take a photograph without a lens, by employing only a simple pinhole as a means of forming the photographic image. It has been found, however, that by using a lens the pinhole can be enlarged, as it were, thus admitting more light, greatly improving the image, and allowing pictures to be made under a great variety of conditions. A lens passes parallel

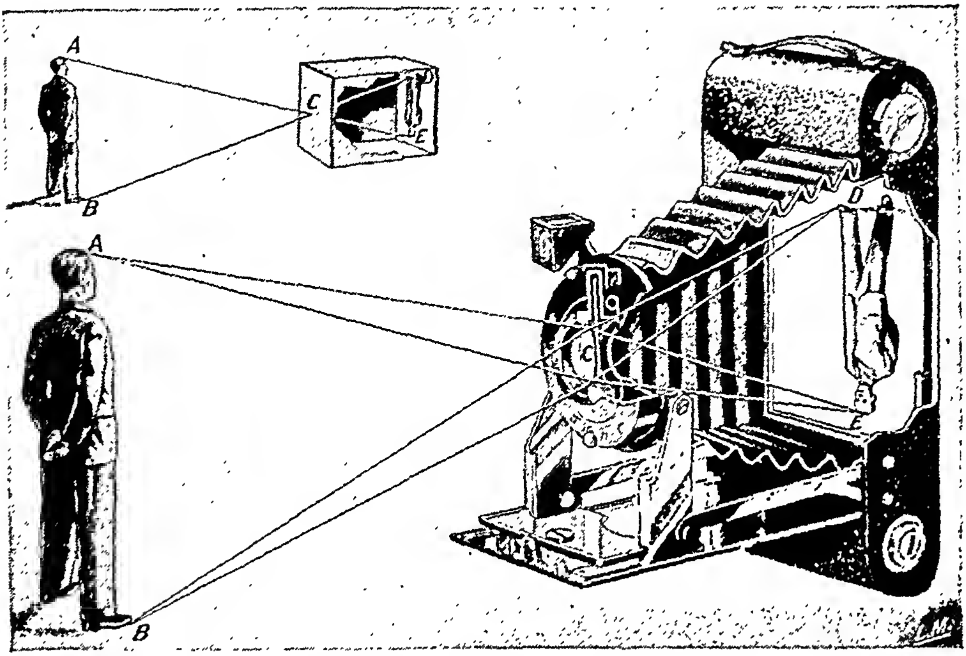


Fig. 18. How a camera takes a photograph. (See text.) A dark box (inset) with only a pinhole in place of a lens will take a satisfactory photograph.

we should see only a minute portion of the image at E. Because our line of vision follows the same straight path as the light ray ACE, the portion we should see would be the head of the man. Similarly, if we placed our eyes level with the point B we should see a fraction of the feet of the man in the image at D, and the remaining part of the image would be seen at intervening places.

To convert such a dark box into a modern camera it is only necessary to replace the pinhole with a lens and to rays of light and these converge at a point, called the "focus", the distance of which from the lens is called the "focal length" of the lens. The longer the "focal length" of a lens, the larger is the image of objects on the film, and consequently the less of the subject will be included in the photograph. Conversely, the shorter the focal length, more of the subjects will appear but the image will be smaller. The further the distance of the object from the lens, the nearer the film must be to the lens;

and conversely, the nearer the object, the farther away must the lens be from the film. It is to adjust these differences that we "focus" a camera. As a rule, modern cameras are fitted with a lens that has a focal length a little longer than the longest side of the film or plate. Thus a $4\frac{3}{4} \times 3\frac{1}{4}$-in. camera will have a lens about $5\frac{1}{2}$ or 6 in. focal length.

PRINCIPLES OF PHOTOGRAPHY

The process by which a photograph is obtained is relatively simple. The light-rays from the Sun fall upon the subject and are reflected in all directions. The rays coming from any single point of the subject therefore impinge at varying angles on all parts of the lens. In passing through the lens they are refracted, again at varying angles, until they all meet at a point. From the point A, (Fig. 18) for example, the rays are reflected to different parts of the lens and are collected together at E, while those from the point B are collected at D. Similarly, rays from every other point of the subject are collected from various parts of the lens and concentrated again somewhere within the plane DE. Consequently, if we place a photographic film at DE a perfect image of the subject will be reflected on it, but if the film is inserted at any other distance the image will be distorted, or "out of focus", to use the technical term.

In many hand-cameras the distance between lens and film is fixed so that the focus is always correct. In more elaborate cameras, however, where it is required to obtain larger images of objects at varying distances from the lens, it is necessary to adjust the focus. This is done by moving the lens to or from the film until the image is defined with maximum clarity. Actually, for the purpose of focussing, the film is removed and replaced by a sheet of ground glass on which the image may be seen. When correct focus is obtained the camera "shutter"—a device fitted immediately before or behind the lens—is closed to prevent light coming through the lens and the ground glass is replaced by the photographic film. To take a photograph it is now only necessary to press the shutter control, so opening the shutter for a fraction of a second and then closing it again. During that fraction of time everything within the range of the lens has been faithfully recorded on the plate, every little detail of light and shade having slightly different effects on the sensitive chemical with which the film is coated.

The chemical usually employed in making photographic film is silver bromide, one of the class of chemicals known as "silver salts" and a compound of the metal silver with bromine. The silver salt is applied to the film or plate in the form of an emulsion that contains the chemical suspended in a gelatine solution. We can obtain an approximate idea of what happens when the light-rays fall on the film if we imagine that the rays tend to separate the compound into its constituent parts of silver and bromine, the extent of this separation varying with the amount of light reaching the film.

WHAT THE DEVELOPER DOES

The rays produce minute changes that cannot be detected by ordinary means and require a developer to render visible the results of the action. Such a developer generally consists of a developing agent, usually pyrogallic acid (pyro), hydroquinone, or metol. Its function is to bring out the latent image by reducing the silver salt to metallic silver —or, to express it less scientifically, by blackening those parts affected by the light. It is because silver turns black under the action of light that photographs are black and white. The

developer also includes an alkali—generally sodium carbonate—that acts as an accelerator and gives a greater reducing power to the developing agent, so speeding-up the blackening process. Finally, the developer contains a restrainer—such as potassium bromide—to prevent the development of the unexposed silver salts and to act as a preservative, preventing the solution from deteriorating, or oxidizing, whilst in use.

After development the negative is immersed in a fixing bath, the effect of which is to make it permanent—that is, to "fix it"—so that it can be brought into the light without risk of spoiling it. This fixing bath—a solution of sodium hyposulphite—dissolves away the remaining compound that has not been affected by the processes of exposure and development.

We have now the finished "negative," in which all the details of the picture are composed of pure metallic silver, the heaviest deposits of silver being at those places where most light reached the film. That is why all the brightest parts of the original appear black, or opaque, when the negative is held up to the light. The dark portions or deep shadows in the scene photographed reflected no light, and therefore as they had no effect on the film they appear white or transparent.

As the film remains sensitive to white light until it has been passed through the fixing bath, all the operations up to that point have to be carried out in a ruby light in the photographer's "dark room". Once the film has been safely fixed, positives or "prints", may be taken from it on specially sensitized paper, as many times as desired.

These prints from the negative are obtained by practically the same chemical processes as those used to produce the negative. The paper is coated with a silver salt so that it is sensitive to light, exactly as the photographic film was, although in this case the reaction is much less rapid. A sheet of this paper is placed in a printing frame in contact with the negative, in which position it is exposed to a strong light for a certain period—perhaps a few seconds. The light-rays pass through the transparent parts of the negative, so affecting the silver salts with which the paper is coated. The dark parts of the negative obstruct the light, leaving the silver salts unaffected. When developed, the picture appears as a positive with all the gradations of light and shade of the original subject in their correct places. Finally, the print is dipped in a fixing solution so that continued exposure to light will have no further effect on the sensitive chemical, and after being washed and dried, it is ready for mounting.

THE ROLL-FILM CAMERA

The most popular type of camera for amateurs on account of its simplicity and portability is that which uses roll film. This is simply a long strip of celluloid coated with the sensitive silver salt. It is placed in the camera between two spools and as soon as a picture is taken the used part of the film can be wound on to one of the spools and a fresh portion brought behind the lens, and so on until the entire roll has been used.

The origin of photography may be traced to Thomas Wedgwood, who early in the nineteenth century discovered a method of obtaining profiles of figures, stained-glass windows, etc., by throwing their shadows on paper rendered sensitive to the action of sunlight by a coating of nitrate of silver. He failed to solve the problem of "fixing" the pictures, however, and it was left to a Frenchman, Nicéphore Niepce, in 1822, to produce the first permanent photograph with the aid of a plate coated

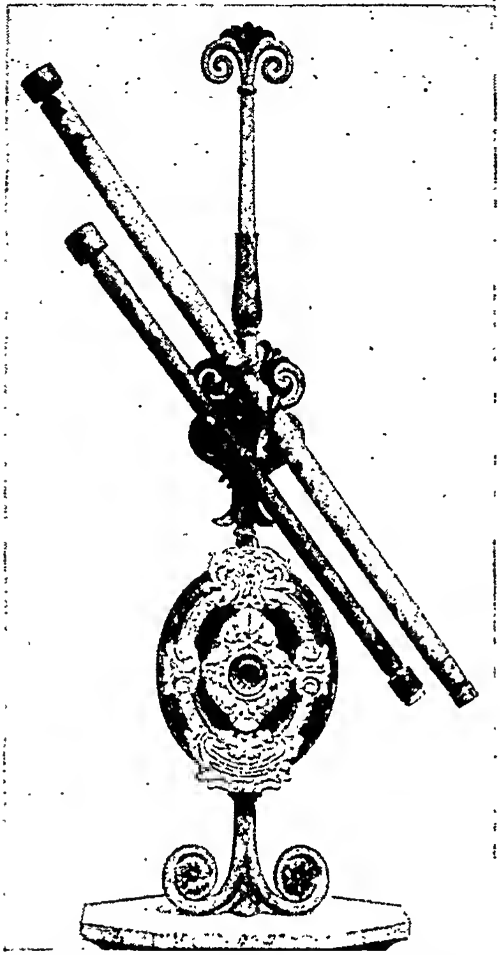


Fig. 19. Two telescopes believed to have been made by Galileo. Mounted in centre of supporting frame is one of Galileo's object glasses.

with silver and bitumen; this was exposed for about eight hours to the image in a camera obscura. The process was improved by Louis Daguerre, who in 1839 produced the first "daguerrotype". In this the subject was taken directly on a copper plate and in consequence the image was reversed. Daguerrotypes could not give copies as modern negatives do, nor were they very clear to the vision unless held at a certain angle to the light. They remained popular for years, however, and no doubt people at that time considered them marvellous.

During the same period Fox Talbot was steadily working in England. Without any knowledge of the previous labours of Wedgwood he discovered (about 1839) a means of obtaining pictures in the camera by the agency of light. He used paper washed with nitrate of silver, and he also discovered how to "fix" the prints when so obtained. He then proceeded to perfect the method by which "positives" or prints, could be made from the original photographic impression, thus introducing a method practically the same as that in use to-day.

THE "MAGIC LANTERN"

A "magic lantern" is the opposite of a camera. In order that the image may appear vertical on the screen, the slide must be placed upside down in the carrier, and slightly beyond the focal distance, at which the light is placed. The condenser, a large convex lens of short focal length, causes the light rays to become parallel and concentrates as much light as possible from the lamp on to the slide. The rays then pass through the lantern slide and through a lens, the purpose of which is to focus the image on the screen.

Both refraction and reflection are bases of the telescope. Let us see something of how use is made of these principles.

It has sometimes been suggested that the principle of the telescope was discovered and in use as far back at any rate as Babylonian times, but this is very doubtful—as also is the claim by Roger Bacon (1214-94), the Franciscan monk of Ilchester, that the invention was known to Julius Caesar, who, when about to invade Britain, surveyed the new country from the shores of Gaul with a telescope! The popular story is that the telescope was invented—not by Galileo as is often erroneously stated, but by an apprentice of Hans Lippershey, an optician at Middleburg

in Holland. According to the story the boy was playing with some spectacle lenses during his master's absence, when he happened so to arrange the lenses that the spire of a neighbouring church was magnified. On Lippershey's return the apprentice told him of what he had seen and the optician made the first telescope in 1608. In the following year Galileo heard of the discovery and set to work and made a telescope, after discovering the principle on which it was based. Later, with improved instruments (Fig. 19), he made numerous discoveries—the spots on the Sun, mountains on the Moon, satellites of Jupiter and many others.

Galileo's telescopes were of the refracting type (Fig. 20). Such depend for their power on the refraction of the rays of the light by a large lens, or "object glass" as it is called. A lens of the single positive type has both surfaces curved and inclined to one another at every part except the centre, where they are *parallel* (Fig. 21). When rays of light, say from a star, enter the lens they are refracted. They are not restored to the same general direction when they leave it, however, as in the case of a sheet of plate glass with

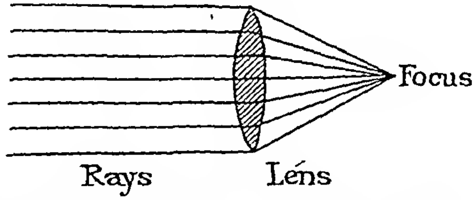


Fig. 21. A single lens, with both surfaces curved, refracts the rays of light to a focus.

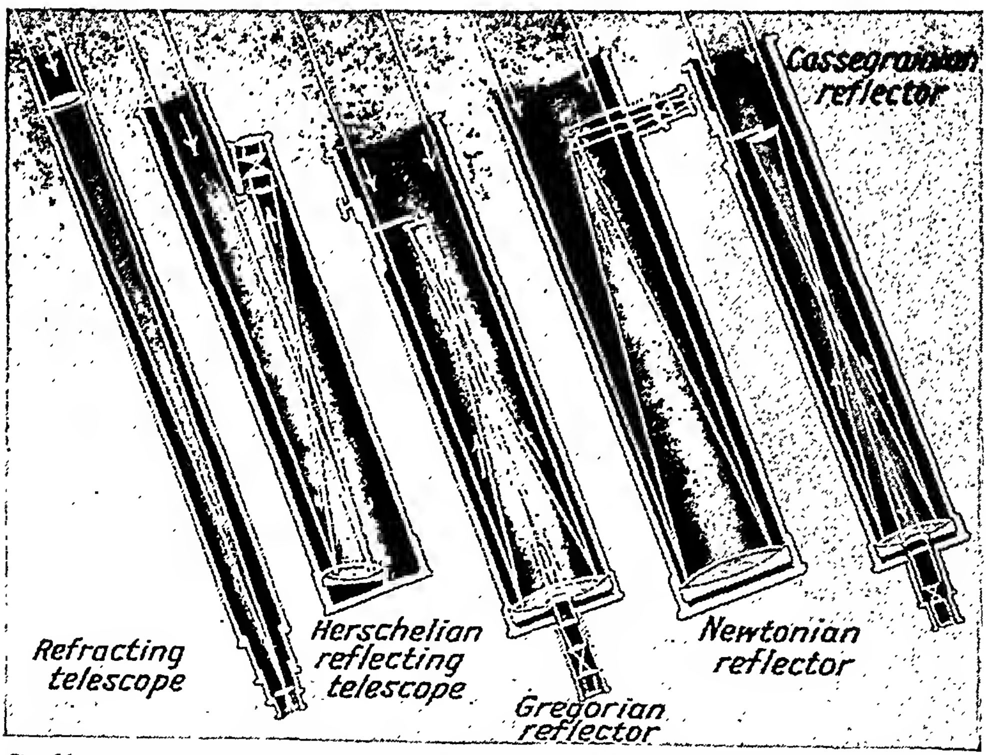
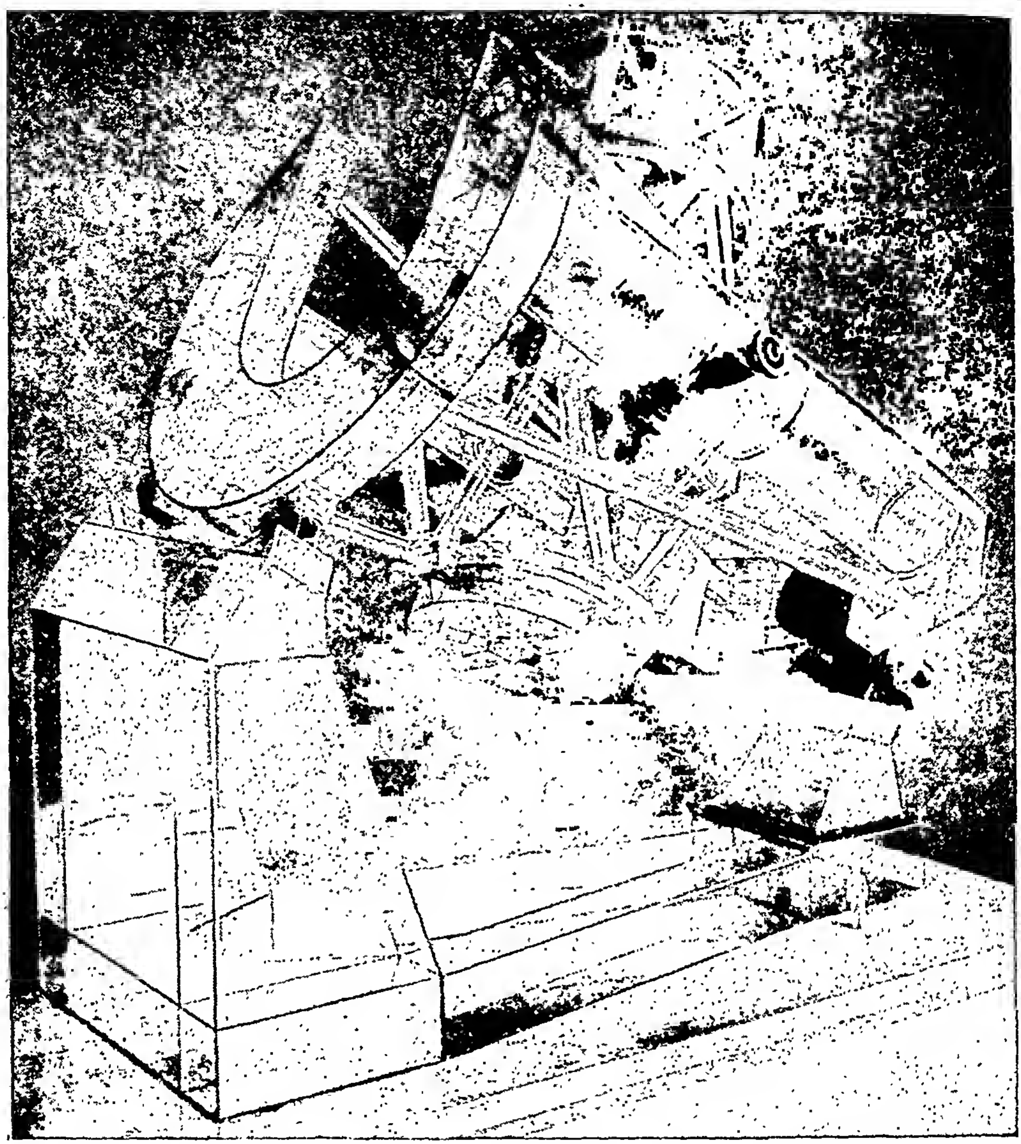


Fig. 20. The two kinds of telescopes. On the extreme left is a refractor ; the others are reflectors. Reflecting telescopes are so called because in them the rays of light from an object are collected on a silvered mirror and reflected to a focus, where a magnifying eye-piece is placed.



An amazing celluloid model of the 200-inch telescope which is to be erected on Mount Palomar. The model was made to scale so that the builders could see the position of every section. An idea of the instrument's dimensions is gained from the human dummy at its base.

parallel surfaces. Instead, the figure of the lens—that is the manner in which the surfaces are fashioned—causes the refraction to become less towards the centre of the lens, where it ceases and the rays pass straight through the glass. Such lenses are made so that all the rays from the star meet at a point called the focus, where an inverted "image", or complete picture, of the star is formed, to be magnified by the eye piece. The fact that the image is inverted is of no disadvantage in Astronomy, for most of the heavenly bodies that we examine can never be seen otherwise than with a telescope. In telescopes for terrestrial use the inverted image is restored to its erect position by inserting additional lenses in the eyepiece.

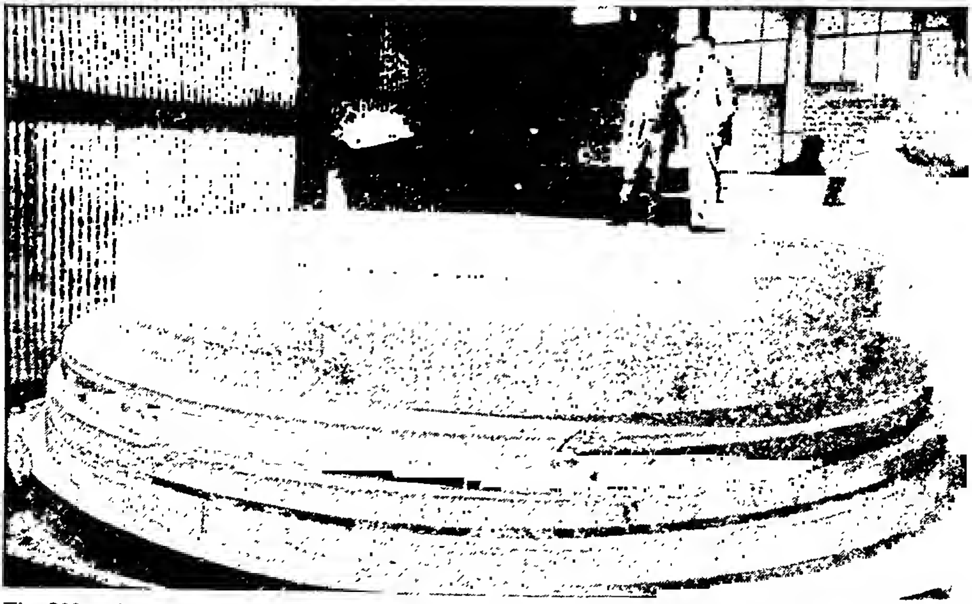
We may regard the light entering a

telescope as a bundle of parallel rays, the size of which depends on the diameter of the object-glass. The lens acts like a funnel in a bottle placed on the lawn to collect rain, which it causes to converge through the neck into the bottle. The larger the funnel-mouth, the more rain collected and the sooner will the bottle be filled. Similarly, the larger the object-glass, the more rays of light will be collected. The effect of the object-glass then is to converge the light-rays to a focal point by refraction. The eye piece which magnifies the image formed by the rays, enables it to be examined with varying powers, according to the requirements of the observer, or depending on what the atmospheric conditions will allow. The arrangement is similar to that of the human eye for it also is a lens-system that receives a bundle of parallel rays from a distant object and brings them into focus on the sensitive retina.

Sometimes people are surprised to find how much even a small telescope will show—say in the number of the stars.

The explanation is not very difficult to find. As the diameter of the pupil of the eye is at the most $\frac{1}{3}$ in., a telescope with an object glass only 1 in. in diameter (equal to a good opera glass) will therefore collect no less than nine times the amount of light that normally enters the eye. To put it in another way—suppose there are two stars one of which is just perceptible to the unaided eye and the other sends only $\frac{1}{9}$ the light of the first. Then the fainter star will become perceptible in a telescope with an object glass 1 in. in diameter.

After Galileo's death larger telescopes were made by different opticians, but as the sizes increased it was found that difficulties increased also. The chief trouble was that the objects seen through these instruments appeared to be surrounded with a fringe of colours, due to what is known as "chromatic aberration".



The 200-inch disc of the Mount Palomar telescope after it had been removed from the annealing oven where it had taken seven months to cool. In case any flaw should be discovered in it, another disc, identical with it, was cast. Each of these discs cost approximately £100,000.

This is caused by the difference in the refrangibility of different kinds of light from any object, the less easily refracted red rays being brought to a focus farthest from the lens, while the violet rays, being more refrangible, are brought to a focus nearer the lens. The effect is to produce a series of differently-coloured images of the object.

In these early telescopes, too, there was another defect, known as "spherical aberration", due to the rays of light that pass through the peripheral part of the lens being refracted in a manner different from that of those passing through the parts nearer the centre. This results in a curved focal plane being formed instead of a flat one.

Huygens, Bianchini, and Cassini endeavoured to overcome the difficulty of chromatic aberration by increasing the focal length of their telescopes, and in consequence these became very unwieldy, some reaching 120 ft. in length. About the middle of the 18th century, however, Chester M. Hall, discovered that chromatic aberration could be eliminated by using a combination of lenses in the object-glass—a convex lens of crown glass and a concave lens of flint glass (Fig. 22). This type of telescope is called the "achromatic" because it is "without colour".

The discovery of the achromatic object-glass has a peculiar interest in that Newton had expressed the opinion that nothing could be done to overcome the chromatic aberration of the single object-glass in the telescopes of his day. Strangely enough Hall, the discoverer of the achromatic, was indifferent to fame and profit and did not even make public his invention. It was left to John Dollond, an optician, to work out (in 1758) the principles involved. Even his work was ineffective for a time, however, for the British Government imposing a crushing duty on flint glass.

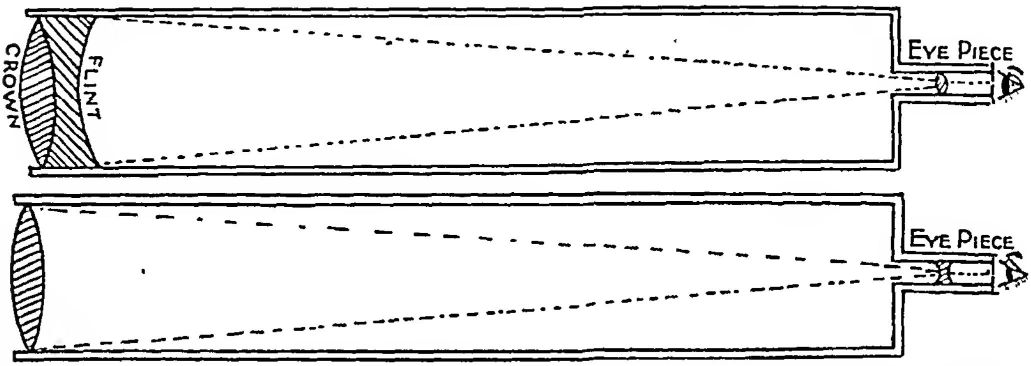
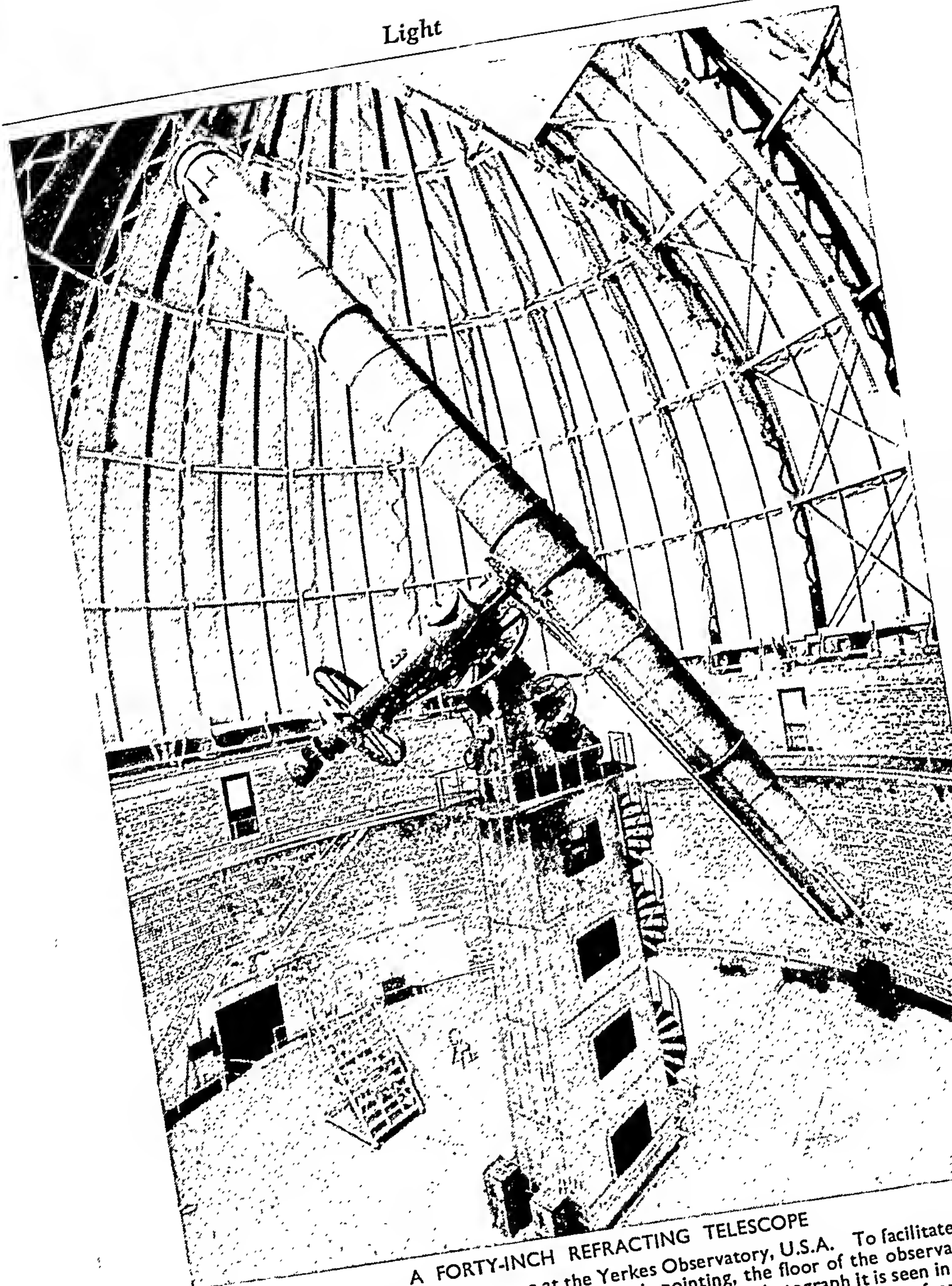


Fig. 22. (Top) The arrangement of the achromatic object-glass: a convex lens of crown glass, and a concave lens of flint glass. (Bottom) Refracting telescope with single object-glass as at first used.

At that time flint glass of perfectly homogeneous quality could only be obtained in small pieces, and discs of even 2 or 3 in. were practically unobtainable. About 1784 P. L. Guinand, a Swiss artisan, commenced to experiment in its manufacture. After seven years of research, during which time he was reduced almost to poverty, he was able to produce discs of from 4 to 6 in. diameter and eventually turned out discs of 18 in.

The secret of his process was of a mechanical rather than a chemical nature that is to say it was a question more of the manipulation of the ingredients than of their quality or composition. After his death the secret passed to his son, and from him to G. Bontemps, a director of a large glass-works at Choisy-



A FORTY-INCH REFRACTING TELESCOPE

Fig. 23. The 40-inch refracting telescope at the Yerkes Observatory, U.S.A. To facilitate ... observa...
...tion according to the angle at which the telescope is pointing, the floor of the ... It is seen in ...
... It is operated by hydraulic power. In this photograph ... Williams Bay, Lake Geneva, Wisconsin, about 65 miles fro...

le-Roi. When revolutionary troubles arose in France in 1848 Bontemps fled to England and settled at Birmingham, where he entered into partnership with Messrs. Chance, the famous glass-workers, to whom he communicated the secret of the Guinand process. This firm subsequently made the lenses of some of the world's largest refracting telescopes, of which the largest is the 40-in. at the Yerkes Observatory situated near Lake Geneva, Wisconsin (Fig. 23).

NEWTON'S REFLECTOR

When Newton decided that it was impossible to improve the refractor and eliminate the defects of the early instruments, he turned his attention to producing an alternative form of telescope, known as the reflector. Light is reflected from a body at an angle that is equal to the angle of incidence, or that at which the ray strikes the reflecting body. The reflecting telescope depends for its power on a mirror with a paraboloidal surface that has the geometrical property of converting a beam of rays into a cone of reflected rays (Fig. 20). These rays converge at the focal point, forming, as it were, the opposite to a motor car headlight or a searchlight, in which a point of light is converted into a broad beam of parallel rays, the width of which depends on the size of the reflector.

Normally the focal point from the mirror of a reflecting telescope is in the centre of the open tube, at the bottom of which the mirror is mounted. This is obviously useless for observational purposes, so Newton introduced a small mirror with a plane surface, at a point slightly nearer the main mirror than the focal point. This is seen in the second telescope from the right in Fig. 20. This small mirror, or "flat", was placed at an angle of 45° to the axis of the large mirror and was held in position in the mouth of the tube by light metal bars, that did not obstruct the passage of the rays entering the mouth of the tube on their way to the large mirror at the bottom. The flat therefore reflected the converged beam from the large mirror to a point at the side of the tube in which a hole was cut to permit the insertion of an eyepiece.

The mirror of the first telescope Newton constructed on this principle (in 1668) measured only 1 in. in diameter and was made of speculum metal, an alloy of tin and copper in the proportion of 1 to 4. This gives a white glassy surface capable of taking a high polish. The next great advance in the construction of reflecting telescopes was made by John Hadley, the inventor of the sextant, who, in 1723, presented the Royal Society with a Newton-type instrument with a mirror 6 in. in diameter. The performance of this comparatively small telescope surpassed that of the earlier type of reflector, even of a focal length as great as 123 ft.

HERSCHEL'S GREAT DISCOVERIES

In the hands of Sir William Herschel the reflecting telescope made possible many important discoveries, including that of Uranus. Herschel's largest telescope had a mirror 48 in. in diameter and a focus of 40 ft. We gain some idea of the difficulties in constructing instruments of this type when we learn that the total thickness to be abraded from the edge of this 48-in. speculum to convert it into a paraboloid is only $\frac{1}{21,333}$ in. On this microscopic difference in form depends the definition and optical efficiency of the instrument.

The largest reflecting telescope ever constructed with a speculum mirror was that erected in 1885 by the Earl of Rosse at Parsonstown, Eire. It had a mirror of 6 ft. diameter and since nothing was known of the process by which Herschel

achieved his results, his secret having died with him, Lord Rosse had to tackle the problem from the beginning. When completed the mirror weighed 4 tons with a focal length of 54 ft., so that the question of mounting it presented almost as great a difficulty as the initial problem. The telescope did fine work, particularly in connection with the observation of the faint nebulae. In this its enormous light-grasp was of great utility.

SILVERED GLASS MIRROR

In 1856 A. Steinheil suggested that glass discs might be used instead of speculum metal for the mirrors of reflecting telescopes. All the large reflecting telescopes made subsequently have had mirrors of glass, ground to the required curvature and having a thin film of silver deposited by a chemical process. The silvered-glass mirror gives a particularly brilliant reflecting surface, reflecting more light than a metallic mirror of the same area in the proportion of 16 to 9. The first large silver-on-glass reflector, made in 1879, had a diameter of 36 in. This was followed by larger and larger telescopes, notably the 100 in. of Mount Wilson (Fig. 24), at present the largest in the world but soon to be surpassed by one of no less than 200 in. aperture.

This extraordinary instrument is now being installed on Mount Palomar, a 5,700-ft. peak situated a hundred miles south of Los Angeles in California. It will be the largest telescope the world has known and will reveal things beyond the wildest dreams of astronomers of even twenty years ago.

Considered only as an engineering work, the construction of this reflecting telescope is an unparalleled achievement. Engineers to-day are able to build a towering skyscraper in a year, or a giant liner in two years. Yet engineers and physicists have required no less than twelve years for the construction of this telescope, from which statement we are able to gather something of the difficulties of the task that lay before them.

Two years of research-work were necessary in connection with the casting of the giant disc of glass that forms the mirror, and during this time experimental mirrors of up to 120 in. in diameter were cast. The casting of the 200-in. mirror itself commenced in 1934, the glass being heated in a 30-ft. furnace for three weeks and maintained at a temperature of 2,800°F. For seven months the disc was annealed, the temperature meantime being gradually decreased at the rate of 1.4°F. each day. This disc, which weighs 25 tons and is 36 in. thick, consists of a special kind of low-expansion glass of the pyrex type. This kind of glass is not as liable to temperature-changes as ordinary glass, and it has a high reflecting power for all wave-lengths of light. The mirror will be so heavy that a special arrangement of honeycombed supports is to be fitted into the ribbed back to take the weight off the sides. Despite its weight, the telescope will move with ease and precision at a touch from the observer, who will be able to "aim" it at will.

THE 200 INCH MIRROR

The grinding and polishing of the mirror, which commenced in 1936, will be completed this year (1939), and whilst four tons of material have to be removed from its surface it must be accurate to one millionth of an inch. When the grinding has been done and the mirror finally tested, a coating of aluminium, four millionths of an inch thick, will be placed on the glass.

This giant "optick tube"—as Galileo called his first little telescope—will bring the Moon to within a distance of approximately 25 miles. It would readily

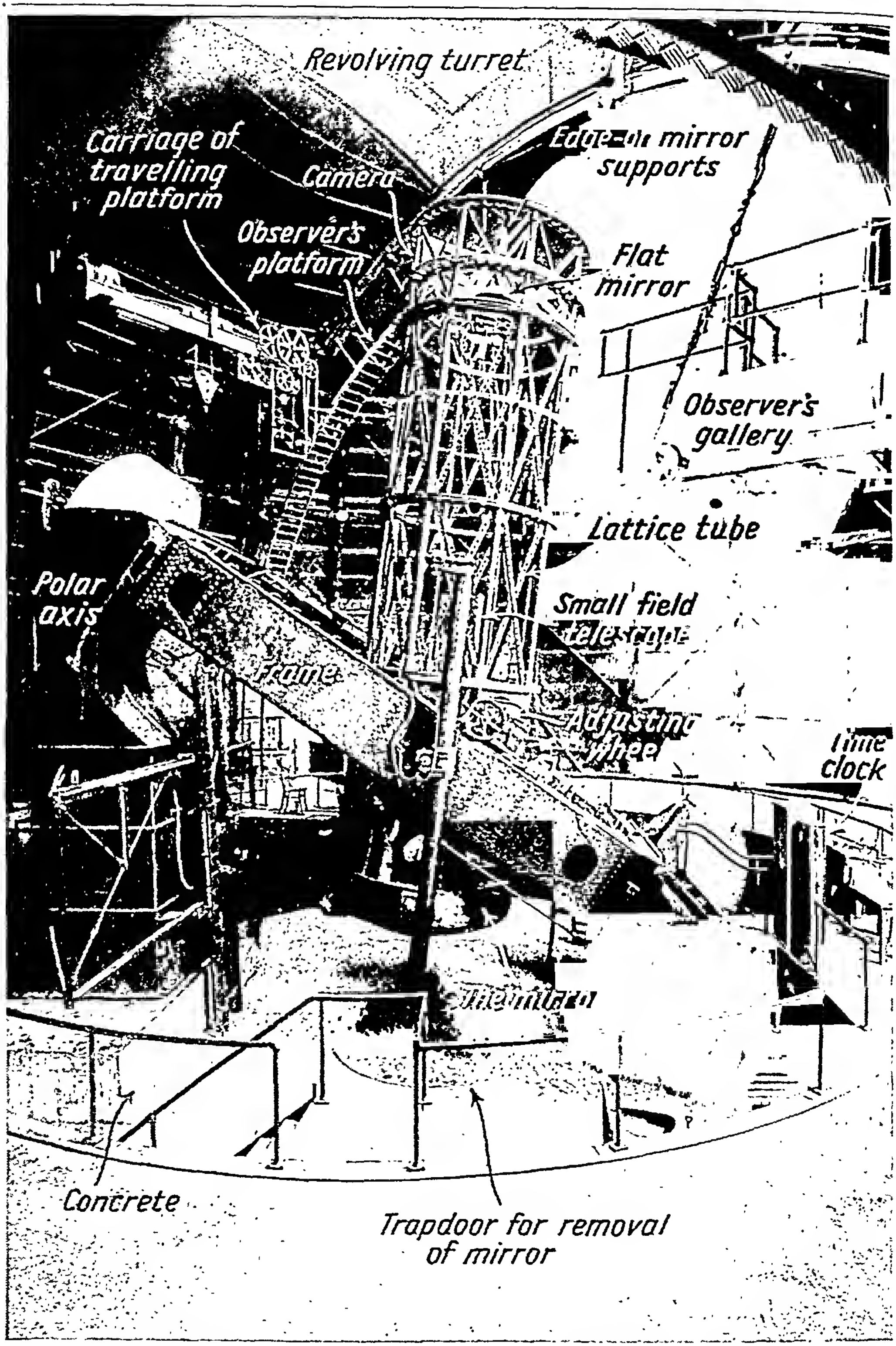


Fig. 24. The 100-inch Mt. Wilson reflector, which collects 250,000 times as much light as the eye.

detect the light of a candle 10,000 miles away in space. If it could be erected in Liverpool and trained on New York it would be possible to tell whether a house had one or two storeys, a discrimination that can be made with the naked eye at a distance of about a mile on a clear day.

The spectroscope is at least as wonderful as the telescope. The telescope enables us to see objects that are invisible to the naked eye, whilst by analysing the light received from these distant bodies the spectroscope enables us to identify the materials that compose these bodies. Not only are we able to bring the stars into our laboratories and to see of what they are made, as it were, but we have been able to advance our knowledge of physics by discovering what is taking place in the stars where there exist conditions of temperature and of pressure that cannot be obtained in any laboratory.

Newton was the first to demonstrate that "white" light is not white, but has a composite character. He inserted a prism in a beam of sunlight that entered a darkened room through a small hole in the shutter. He noticed that the light from it fell on a screen, not as a patch in the shape of the hole in the shutter, but as an elongated band of coloured light (Fig. 1). From this experiment it appeared to Newton that white light must be composed of several colours, and that these were acted on in different ways by the prism, some being refracted more than others. He tested the idea in a simple yet ingenious way, by making a small hole in the screen itself to allow only one of the colours of the refracted beam to pass through. Inserting a second prism in its path he found, as he had expected, that the single constituent of the main beam was not further dispersed by the second prism. It was deflected, of course, but could not again be divided up because it was itself a simple ray of light and so differed materially from the compound ray of which it originally formed part. Although at the time Newton had no idea of the far-reaching importance of these experiments, his discovery laid the foundation of spectrum-analysis, the analysing of light from a given body.

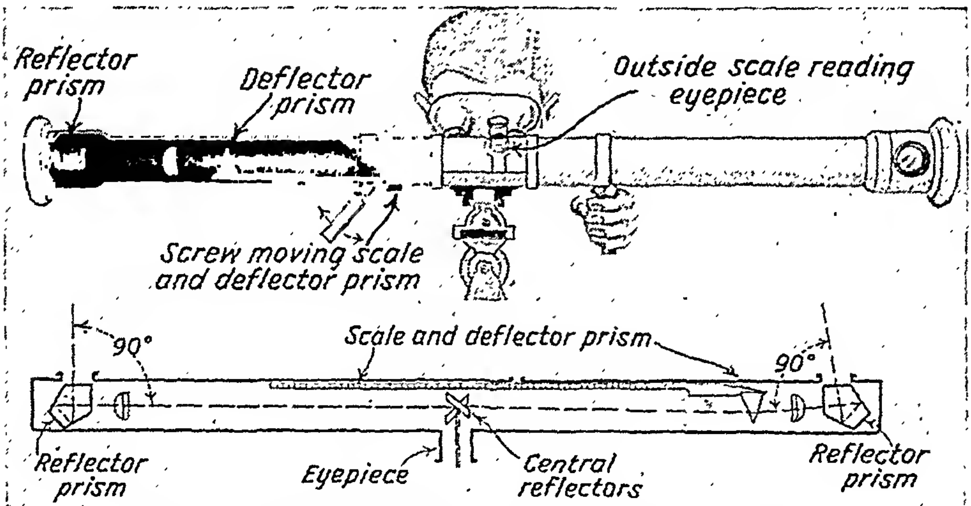


Fig. 25. How reflector and deflector prisms are used in range-finders.

A prism is a solid body, the ends of

which are any plane figures that are similar, equal, and parallel. Therefore the base of every prism is equal and similar to any section parallel to the base. There are several kinds of prisms named according to the figures of their bases, such as square or triangular. Prisms may be regular or irregular, depending on whether their bases form regular or irregular polygons. The axis of a prism is an imaginary line drawn from the centre of one end of the prism to the centre of the other end. Prisms are used in a great many instruments in industry and science—in view finders of cameras, in prismatic binoculars, in range finders, ophthalmoscopes, spectroscopes, etc. The use of the prism in a range-finder is fully illustrated in Fig. 25, on the preceding page.

When white light is passed through a prism, as in the spectroscope, the light is analysed, or split up, into its component rays, which show as seven colours (Fig. 1). We might have expected that the beam of light would have been refracted as a whole and merely deflected from its original course. Owing to the triangular shape of the prism, however, the light that falls on one of the faces is refracted at the first surface and also at the second. The second refraction does not, however, bring the ray into a direction parallel with the original ray—as in a piece of sheet glass, in which the surfaces of the glass are parallel. Instead, it emerges divided into its several component colours, of which those at the red end are the least refracted and those at the violet end most. Incidentally, if the separate rays of the spectrum thus obtained are passed through a convex lens by which they are again refracted, or if they are collected by a concave mirror by which they are reflected, they will collect and reproduce white light at the focus of the lens or concave mirror.

The range of colours produced by a prism is called the spectrum, the component colours of which are red, orange, yellow, green, blue, indigo and violet, the colours merging imperceptibly into one another. Every kind of light has its characteristic lines in the spectrum. For instance, even to the eye the light from a lamp becomes a pronounced yellow if we introduce a quantity of table salt into the flame. If this light be examined through a spectroscope it will be seen to consist of two bright yellow lines (Fig. 26, bottom). To the chemist, table salt is sodium chloride, so that the two yellow lines in the spectrum are thus associated with sodium when vaporised by excessive heat.

USE OF THE SPECTROSCOPE

To carry the matter a step further: suppose we directed the spectroscope to a certain star and—to quote an imaginary example—found that the resulting spectrum showed only these two bright yellow lines, we should be justified in coming to the conclusion that the particular star examined was nothing less than a flaming ball of sodium (Fig. 26, top). As each element in vapour form has its characteristic set of lines in the spectrum, and as these lines have been identified by comparison with the respective elements in laboratory experiments, it is not difficult to understand how we can identify the corresponding elements in the spectrum of a star or other heavenly body.

An examination of the solar spectrum shows us that many of the chemical elements found on the Earth exist in the Sun—calcium, carbon, chromium, copper, hydrogen, iron, lead, magnesium, nickel, potassium, silver, sodium, tin, and zinc, to mention only a few. After all, this is only what we should expect, for, as we have seen, the Earth was formed from the same cloud of

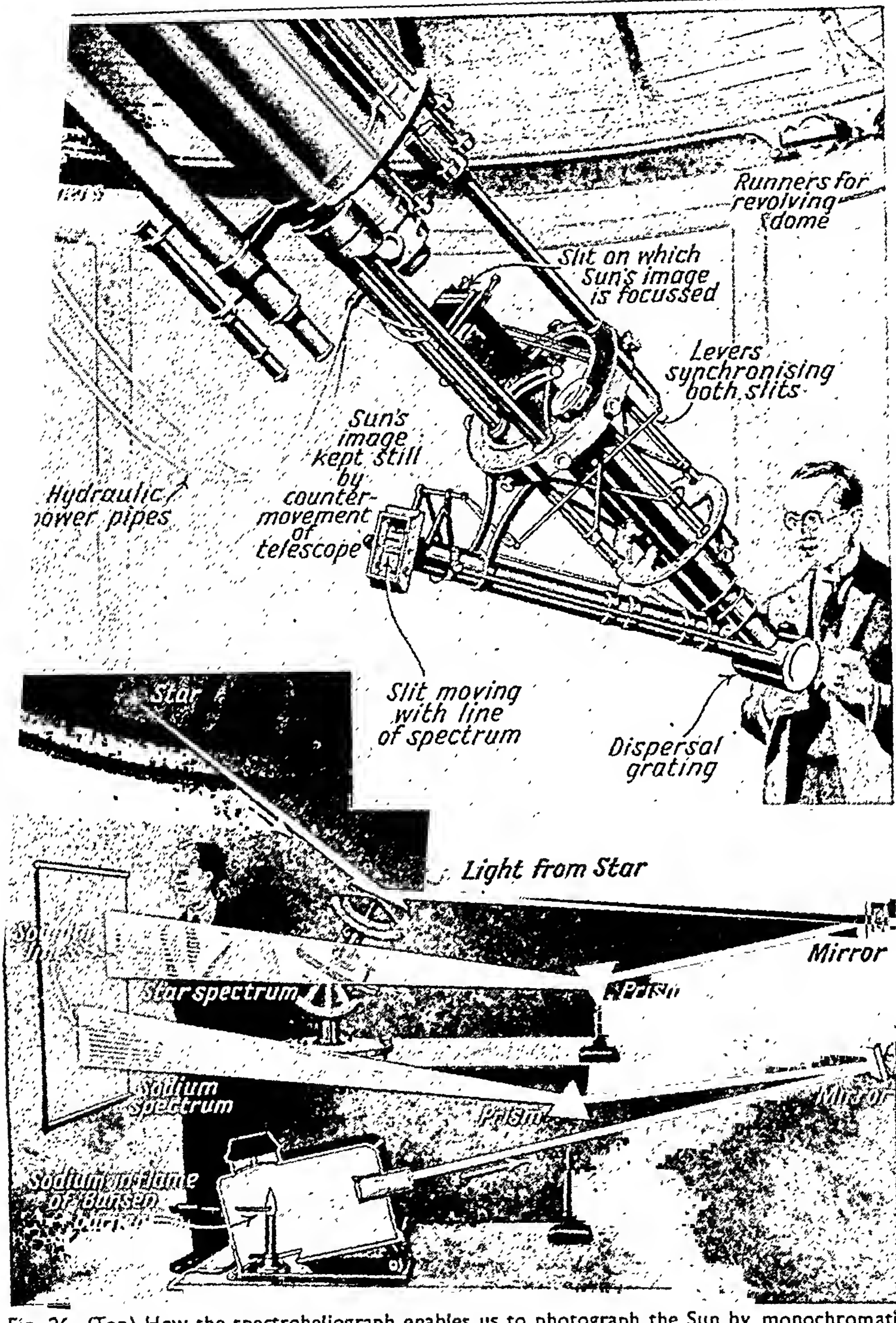


Fig. 26. (Top) How the spectroheliograph enables us to photograph the Sun by monochromatic light. (Bottom) The spectroscope analyses the light from a star, and shows the characteristic lines of sodium. It is identified as such by comparison with light from a lantern in the flame of which sodium is being burned. The lines of sodium are yellow in colour.

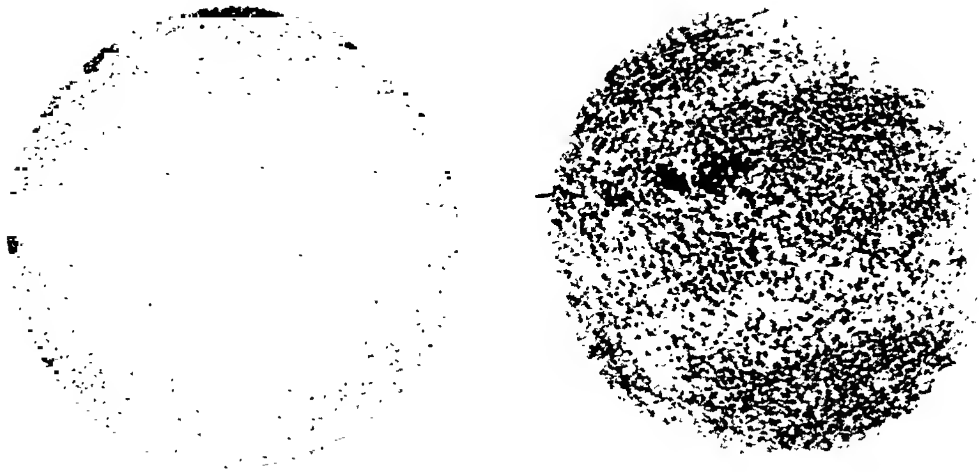


Fig. 27. (Left) The Sun photographed through a telescope, and (right) through the spectroheliograph, with the monochromatic light of hydrogen. In the latter photograph great masses of this glowing gas are seen surrounding the sunspots. Without the spectroheliograph, the presence of these hydrogen areas could not have been ascertained in this way.

gas, or nebula, of which the Sun is the remaining constituent.

In this connection it is interesting to remark that an orange-yellow light seen (by P. J. C. Janssen, a French astronomer) in the solar spectrum during an eclipse in 1868, and thought at the time to be the characteristic lines of sodium, was later found to originate in an unknown element, which was named "helium". In 1894, some 26 years after its discovery in the solar spectrum, Sir William Ramsay, when spectroscopically examining a volatile gas he had obtained from the rare mineral clevite, found the same orange-yellow ray, showing that helium exists also in the Earth. Next to hydrogen, helium is the lightest gas and since it is non-inflammable it is specially valuable and safe for use in airships and balloons. In the United States, and also in Canada, supplies of helium are obtained from a natural gas. The first airship to use helium was the C7 of the U.S. Navy.

A development of the spectroscope is the spectro-heliograph (Fig. 26, top) by means of which the Sun may be photographed only by the monochromatic light of certain gases, such as calcium or hydrogen. To express it another way, a photograph of the Sun taken by the light of hydrogen alone will show only hydrogen; taken by the light of calcium, the result is to show only calcium. Such an arrangement is obviously of the greatest value in a study of solar physics (Fig. 27).

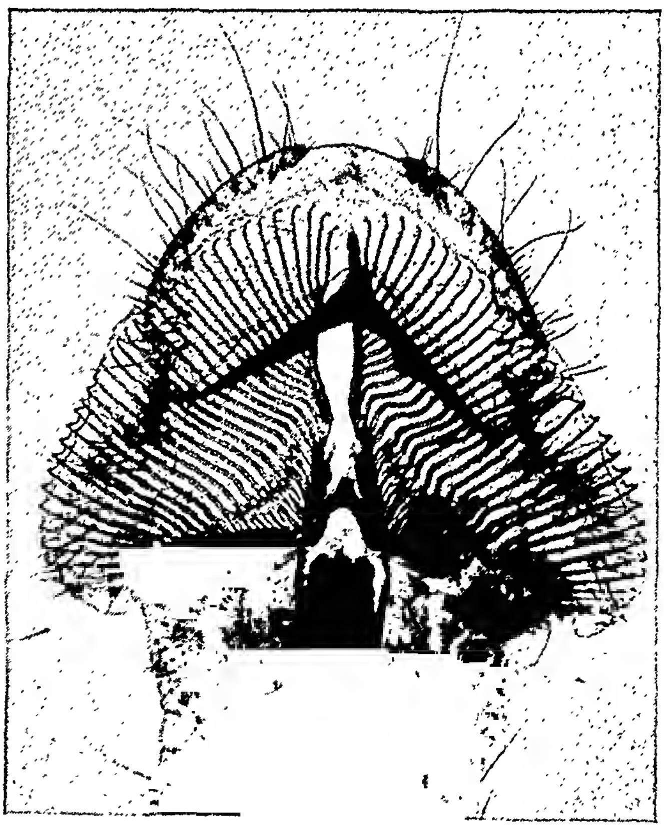
WHAT THE SPECTRUM TELLS US

Moreover, further details in the spectrum enable us to determine several other facts about the body from which the spectrum comes. Without going too deeply into the matter, we may say that it is possible to determine whether the body being examined is in a solid, liquid, or gaseous state, and whether under compression. We can also tell when light from a solid or liquid body passes through a gas, in which case the characteristic light of the solid body is absorbed by the gas, thus causing a different appearance from the normal in the resulting spectrum. In such a case we can tell also whether the solid body is at a higher temperature than the gas surrounding it, or vice versa.

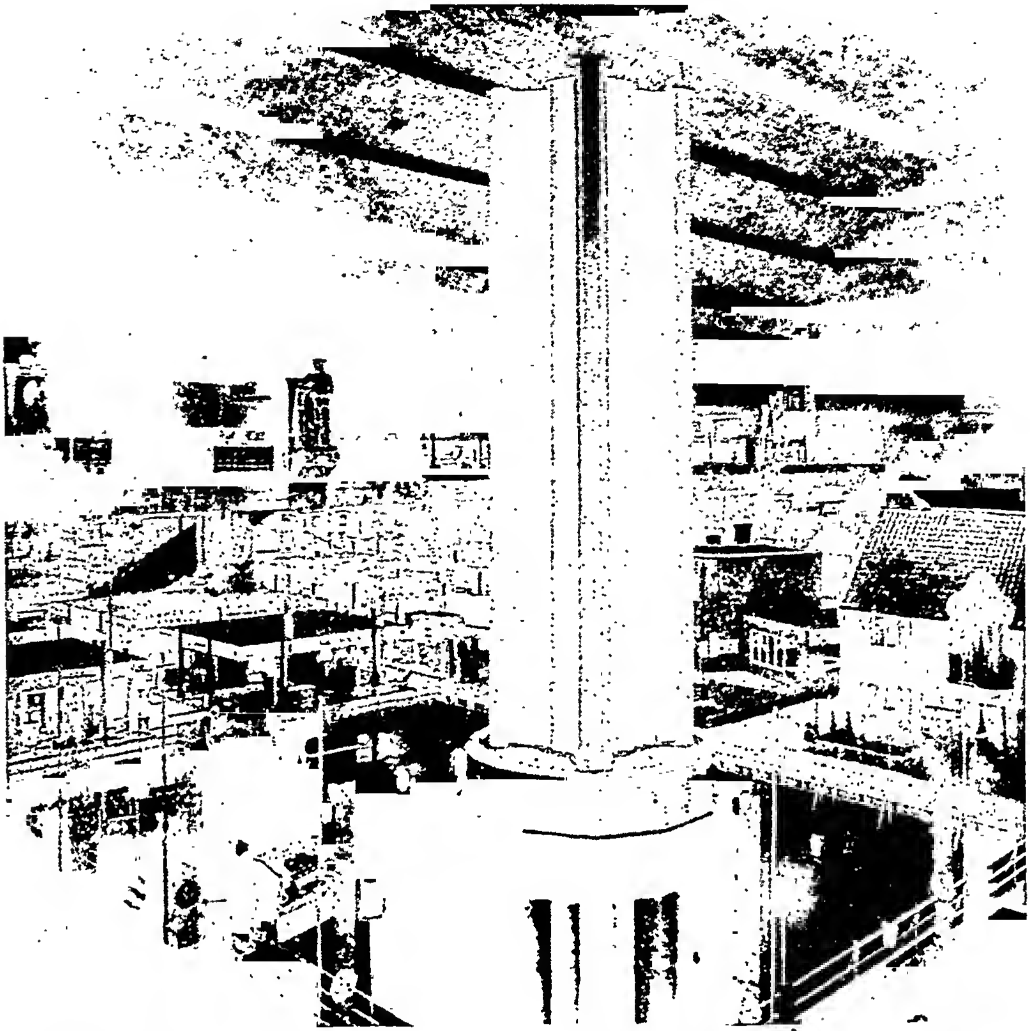
Another important detail is that the spectroscope can tell us whether a star is moving away from, or towards, the Sun—it even enables us to calculate the approximate speed of recession or approach of these stars. To explain how this can be done we refer back to that part of our section on sound in which we mentioned the fact that the pitch of a sound increases if the observer or the source of the sound is in relative motion. We mentioned as an example the increase in pitch of the whistle of an approaching express. The difference in pitch is readily recognisable in the case of sound, since its speed of travel is relatively slow.

In 1842 Christian Doppler, an Austrian physicist, stated that the same principle would apply in the case of light-waves, the velocity of which is nearly a million times greater than that of sound-waves. As the frequency of light-waves determines the colour or tone—as that of sound determines the pitch or tone—Doppler suggested that the colour of a luminous body would be changed by movements of approach or recession. To a certain extent Doppler was right, but he went astray when he applied the principle in the endeavour to ascertain by their colour the velocity of the stars moving towards or from the Earth. He omitted to take into consideration the double range of invisible vibrations that to the eye exactly compensate for the changes in the visible rays.

The principle of the Doppler effect is briefly this. If we are travelling towards a source of light that is emitting light-waves of a particular wave-length in our direction, we meet more light-waves per second than would be the case if we were stationary. The effect there is that the wave-lengths of the light are shortened. If we are receding from the source of light the wave-lengths are increased. A standard for reference for the lines in the spectrum of a star is obtained in the laboratory and is placed alongside the stellar spectrum. If the star is moving towards us, every wave-length of the light received from



Microscopic photograph of a fly's proboscis. With a powerful microscope objects that measure no more than $\frac{1}{250,000}$ of an inch in diameter can be made visible to the human eye or a camera.



The Kaleidakon at Earl's Court, 1939. This amazing instrument is a combination of an organ that produces sounds without pipes and of a light-console on which one plays light as one would play music. A description of the Kaleidakon is given on page 279.

the star will appear shorter than it would be if the star had no motion towards us. The effect is that the whole spectrum is moved slightly, the rays at one end being shifted into invisibility while the rays at the opposite end are rendered visible, or vice versa as the case may be.

In the spectrum of a star that is moving towards us, the lines are displaced towards the shorter wave-length—that is towards the violet end of the spectrum. On the other hand, if the star is receding the displacement is towards the red end of the spectrum. By carefully measuring the amount of such displacement, the velocity of the star's approach or recession can be determined. To mention only two examples, the Doppler effect shows that the bright star Arcturus is approaching us at over 40 miles a second, and that Aldebaran is receding from us at 45 miles a second.

Such is the delicacy of modern observations, that the spectroscope will not only show in the heavens that a nebula is receding from us at a speed of

15,000 miles a second—about a million times the speed of an express train—but it will also detect in the laboratory the presence of $\frac{1}{3,000,000,000}$ part of an ounce of lithium.

Let us now see something at the other end of the scale, leaving the telescope that enables us to explore the heavens and the depths of space, and turn our attention to the microscope by which we are able to explore the mysteries of the unseen world around us. The microscope also depends on the refraction of light, and it seems little short of marvellous that we can use this principle equally well for learning about the greatest and the smallest objects.

INVENTION OF THE MICROSCOPE

The actual date of the invention and the name of the inventor of the microscope is not known. As early as the first century, Seneca—the tutor of the infamous Roman Emperor Nero—noticed that if a globe of glass be filled with water, writing seen through it appeared larger than it actually was. The first mention of lenses for magnifying purposes appears to have been made in 1276, when Roger Bacon showed how crystal lenses could be used to make objects appear larger. "With these lenses", he wrote, "an instrument could be made, useful to old men and to those whose sight is weakened, for by means of it they would be able to see letters, however small they are, made large and clear". It is believed that the first microscope was made at some date between 1590 and 1607 and that credit for the invention must be given to one of three spectacle makers of Middleburg in Holland—Hans Janssen; his son Zacharias; or Hans Lippershey, whose work in connection with the telescope we have already mentioned.

The man who made the best use of the microscope in these early days was Anthony van Leeuwenhoek, who was born in the middle of the seventeenth century near Delft in Holland. He was a humble draper but science was his hobby and his discoveries opened up a new world with infinite boundaries and undreamed-of mysteries. By a fortunate accident he came into possession of a strange instrument consisting of a long tube with a lens at each end—one of the early microscopes. With it he examined everything he could lay his hands on—nothing was too commonplace for his attention. He found life almost everywhere—in dust, earth, and sea water he found myriads of little animals—or *animalcula*, as he called them—and everything seemed to be teeming with life. Even blood was no longer a rich red fluid but a yellow liquid in which floated coin-like discs. Flesh was not merely pulp but was composed of a mosaic of countless millions of minute round bodies that we now call "cells". He saw that insects and worms were not merely moulded masses of a structureless substance but were marvels of beauty and perfection. His neighbours thought he was crazy, but we know to-day that had there been no Leeuwenhoek there might have been no Pasteur and no Lister. The great benefits they conferred on mankind might never have come about when they did, and microbes and bacteria might have continued their harmful activities unchecked by modern science. That we have been able to understand the causes of the diseases they produce, and also the good uses to which they can be put—as in fermentation, for instance—is due to the refrangibility of the rays of light by glass.

Now, how is it that a microscope magnifies small objects? To explain this we must realise that there is a limit

to the nearness at which an object can be focused by the eye. Generally this "limit of distinct vision" is reached when objects are about 10 in. from the eye. What happens is that a microscope assists the lens of the eye to focus clearly objects that are closer to the eye than the limit of distinct vision.

An ordinary reading glass is, in effect, a simple microscope. It consists of a single lens that is brought to bear on the object to be examined. Rays from the object are refracted by the lens to a focus at the observer's eye, as will be clear from Fig. 28. By a simple microscope such as this an object may be magnified from 10 to 20 times, and even this comparatively low magnification reveals many details that cannot be seen with the naked eye. In this form simple microscopes of one lens have many uses as magnifiers to assist in the dissection of animal or vegetable tissues, and for other such simple requirements. Lenses of this kind could be made to give a higher magnifying power, even up to 80, but in such a case the object to be examined would have to be placed very close to the lens and the eye would have to be equally close on the other side, which would be inconvenient. Then again there would be the serious difficulty of chromatic and spherical aberration, that occurred in the early telescopes before the achromatic lens and which has already been described.

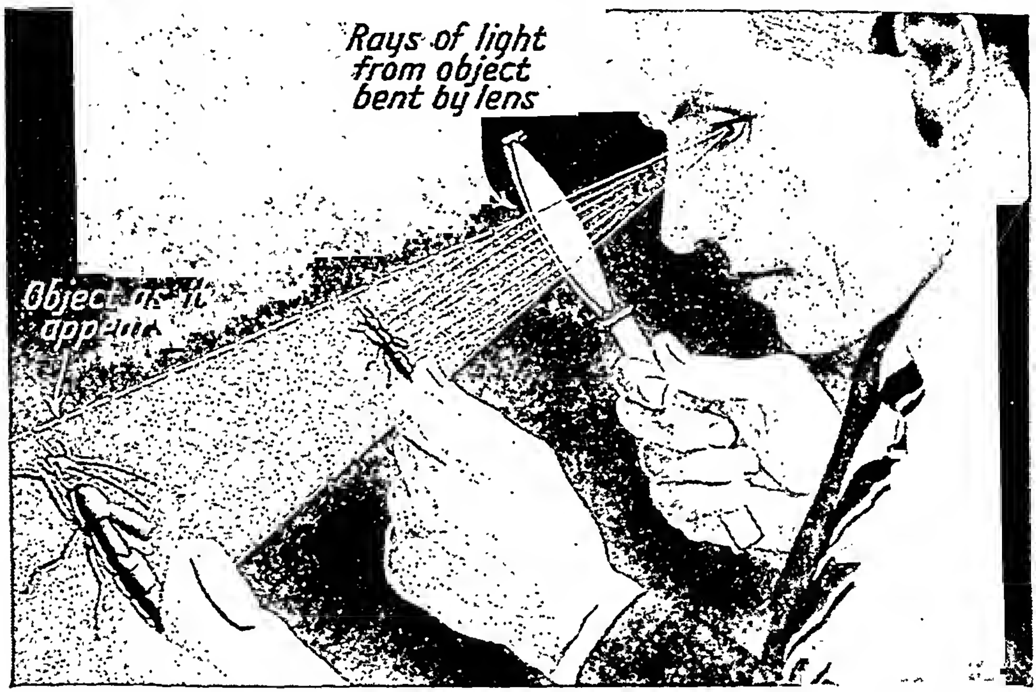


Fig. 28. How a simple magnifying glass increases the apparent size of an object. A microscope such as this magnifies an object from 10 to 20 times its normal size.

To overcome these defects the compound microscope was introduced. In this instrument the essential features are—as its name suggests—a series of compound lenses of crown and flint glass, exactly as is used in the achromatic telescope.

The elimination of both chromatic and spherical aberration is effected in the objective as it is in the telescope. The concave lens of flint glass, having a greater dispersive power, allows two

...rkings of a compound microscope.

colours to combine into light that is approximately white, so that there may be a combination of yellow and green rays at one point. More than this the combination could not do, however, and the result is that the remaining uncorrected colours form what is called the "secondary spectrum". Subsequently, this, too, was eliminated by the use of special optical glass of different refractive indices, introduced as the result of the researches of Ernst Abbe, who worked in conjunction with Carl Zeiss and Schott at Jena. (Abbe was first a director and later after the death of Zeiss, sole owner of the great Zeiss optical works.) Those combinations of lenses that remove the secondary spectrum and correct spherical aberration are known as apochromatic objectives, or apochromats.

THE COMPOUND MICROSCOPE

In the compound microscope the objective forms an enlarged image of the object, and this is further magnified by the eye-piece as though it were a real object being examined with a magnifying glass. Each of the lenses of the objective and the eye-piece may be compounded —that is to say, they may be made up of more than one lens of flint and crown glass. For example, objectives are generally made up of two or three achromatic lenses.

The objective is placed at one end of a tube and the eye-piece at the other, the tube being raised or lowered by a screw or rack-and-pinion movement so that the objective may be brought to the required distance from the object under examination (Fig. 29). The whole is mounted on a rigid stand that also supports a stage on which the object is placed. A hole in the stage allows light to pass, the light being concentrated from a mirror by a sub-stage condenser.

With a powerful microscope objects that measure not more than $\frac{1}{250,000}$ of an inch are clearly revealed to the human eye or photographic plate. A drop of water from a pond may be so magnified as to become a world in itself, with diverse specimens of minute animal and vegetable life, the construction and origin of which present problems of such difficulty that even to-day they remain numbered among the mysteries of science.

In 1931 Dr. Raymond Rife of San Diego brought out a microscope with a working magnification of 17,000 diameters. This instrument easily rendered visible the germs of the staphylococcus, 25,000 of which go to make 1 in. Two years later Dr. V. K. Zowrykin introduced a new principle to optics with his "television microscope". He has pointed out that although there is no method by which we can magnify the light of a candle many thousand times, it is comparatively easy to magnify an electric current billions of times. In his microscope, therefore, he proposed first to convert light waves from an object under examination into electrical waves, then to magnify them, transform them back into light waves, and then to view them. With such an arrangement he expects to show the infinitesimal viruses of influenza, pneumonia, and infantile paralysis. Despite the fact that all these are so minute that they pass through the finest porcelain filters as easily as mosquitoes pass through wire netting, Dr. Zowrykin promises photographs of these creatures on such a scale that they will look like giant insects!

CHAPTER 14

MAGNETISM AND ELECTRICITY

EVERYONE is familiar with the magnet, a small example of the horse-shoe variety of which can be bought at any toy-shop for a penny. Even one of these toys will teach us much about the great principles on which many ingenious devices are based and on which we depend for many things in our everyday life, from the tramcar and the telephone to electric light and television.

Natural magnets—so called because they possess magnetism when taken from the Earth—were familiar to the ancients in the form of lead-coloured stones, now known as oxide of iron or magnetite. The Chinese discovered that if a piece of this ore is suspended so as to hang freely, it will assume a position pointing north and south. From this fact it was called the " lodestone", meaning "leading stone", because it led them in a desired direction.

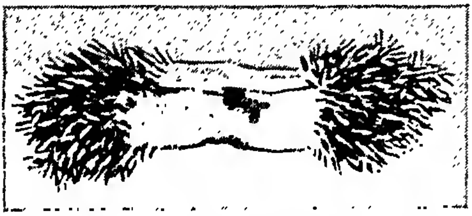


Fig. 1. If a piece of magnetite be dipped into a box of iron filings, the filings cling to its extremities, leaving the middle bare.

Magnetite occurs in Magnesia, a province of Lydia, and from this is derived the name "magnet". The ore was found later in other places—particularly in Sweden, Arkansas, and Spain—in irregular crystalline fragments and occasionally in thick beds.

If a piece of this ore is dipped into a box containing iron filings, it will be found that the filings cling in greatest numbers to the ends of the lodestone, whilst the centre part is without filings (Fig. 1). This shows that the attractive force is greater at the two ends than at others, and these points of greatest attraction are called the "poles".

An artificial magnet may be made from a bar of iron or steel by stroking it with another magnet (Fig. 2). For instance, it is quite a simple matter to make a needle or a knitting needle into a magnet by stroking it in this way, provided the strokes are always in the same direction—either left to right or right to left. Because iron does not retain its magnetism for any length of time, steel is used when a permanent magnet is required.

A magnet may be either in the form of a straight bar or shaped as a horse-shoe—which is simply a straight bar bent; and these are the commonest forms (Fig. 3). Of the two, the horse-shoe type is the stronger and will lift about three times as much weight as a bar magnet. The reason for this is that the attractive power of the two poles is combined, owing to their being nearer

Fig. 2. Magnetising a needle by stroking it in one direction with a permanent magnet.

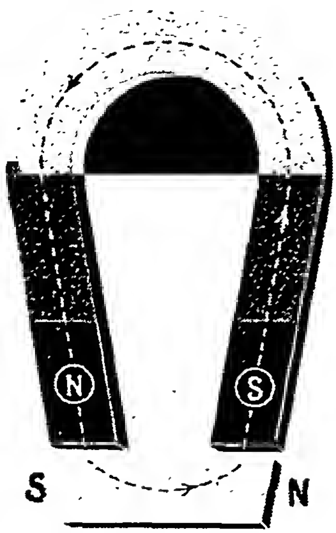


Fig. 3. A horse-shoe type magnet and its keeper, which is placed across the ends of the poles to assist in preventing the loss of magnetism when the magnet is not in use.

together. When not in use, a small piece of metal, called a "keeper", is kept across the poles of a horseshoe magnet to help to preserve its strength. Magnets may also be in the form of a continuous ring, or a disc of iron or steel but neither of these shapes are often seen, being used in the laboratory.

Artificial magnets also have poles. In a bar magnet the poles are at each end of the bar and here are the points at which the attraction is greatest, there being practically no attraction at the centre (Fig. 4). The same remarks apply to natural magnets.

If a magnet or a magnetised needle is allowed to swing freely, as when suspended by a strand of silk or a hair or placed so as to be free to rotate on a point, it will point towards the north pole of the Earth (Fig. 5). This property is the basis of the mariner's compass. The Chinese used the magnetic compass nearly 3,000 years ago, and it would seem that the knowledge of the compass spread from them to the Arabs, who in turn introduced it into Europe. Exactly when this was we do not know, but a primitive form of compass was used by European sailors in the twelfth century. It consisted of an iron needle that had been stroked with a lodestone. It was placed on a pivot, or floated on water, so that it could turn freely, and in this manner was able to come to rest in a position that was approximately north and south.

The modern form of the mariner's compass is due to the work of Lord Kelvin, who perfected it towards the latter half of last century. He replaced the long heavy needle of the earlier compasses with the present short needle. In the centre of the card is an aluminium ring carrying a highly polished sapphire to reduce friction. The needle itself consists of eight thin magnets—steel strips measuring from 2 to 3¼ in. in length and strung together by fine silk threads. These in turn are attached to 32 silk threads that extend radially from the aluminium ring to the centre disc that pivots on the sapphire.

The first study of magnetism was carried out by Dr. William Gilbert, who made the subject his life-work. In 1600 he

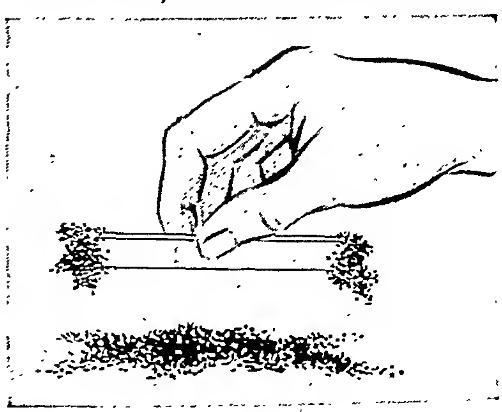


Fig. 4. Bar magnet with poles at ends.

published his researches in *De Magnete*, the first great work on physical science to be published in England. Gilbert explained not only why a compass needle took a definite direction but also the "magnetic dip", as it is called, a matter that had been noticed before Gilbert's time, and to which we shall refer later.

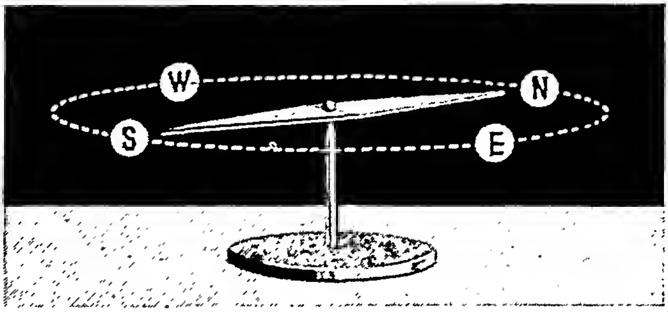


Fig. 5. When a magnetised needle is allowed to swing freely on a pivot, it will always come to rest in a North-and-South position.

If two magnets are hung side by side it will be seen that the two south poles repel each other (see Fig. 9, page 202); whereas if the north pole of one magnet is placed near the south pole of the other, they attract each other (see Fig. 10, page 203). This is in accordance with the well-known law of polarity that "like poles repel and unlike poles attract each other".

Every magnet has two poles and no magnet can exist without two poles. This can easily be proved by magnetising a bar and testing for polarity with another magnet as described above. Now, if we break the bar in half we do not find that we have one magnet with north polarity and one with south polarity. Instead we have two smaller magnets, each with a north and south pole (Fig. 6). No matter how many times we repeat the process and subdivide the magnet—even if ground to powder—the result is always to produce smaller and smaller magnets, each complete with its north and south pole.

Whilst we cannot make a magnet with only a north pole or south pole, we can make a magnet without any poles, for a magnetised steel ring will conform to this condition. The ring shows no magnetism, however, until it is cut and a gap is made. In this gap a magnetic force is developed, and, of course, north and south poles are then present.

As we have seen, there are two kinds of magnetism, or two kinds of magnetic poles that attract and repel each other. One pole tends to swing towards the Earth's north pole and the other to the south pole. Now, the Earth itself posses the property of a huge magnet having a magnetic north and south pole.

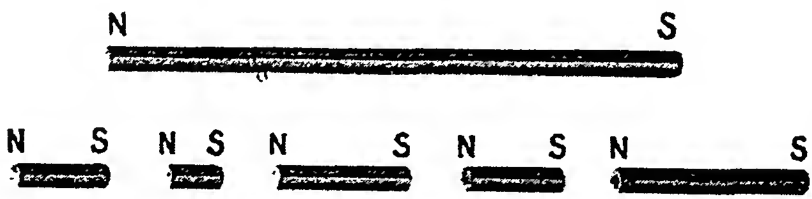


Fig. 6. If a magnet is broken into small pieces, its north pole remains "north", but a new south pole is developed. If broken into smaller pieces, the poles are again distributed as before.

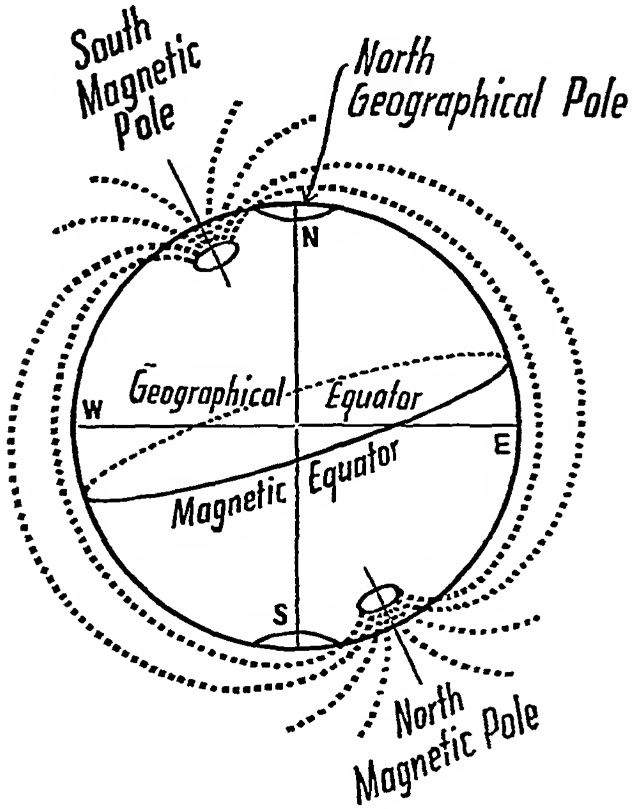


Fig. 7. Showing the positions of the Earth's Magnetic Poles and Magnetic Equator, in relation to the Geographical Poles and the Geographical Equator. For further explanation see text.

It is because of this that the magnetised needle of the compass points to the north, for the magnetic pole of the Earth attracts the dissimilar pole exactly as in the case of another magnet.

Here is a curious fact that is apparently contradictory and has puzzled many people. The magnetism of the Earth near the north pole would appear to be of the opposite kind to that of the pole magnet it attracts. Despite this, as we have seen, it is the north pole of a magnet that is attracted to the north pole of the Earth. We can easily see that this state of affairs would be put right if the attracted pole of a magnet was marked "south", but this would be "begging the question". The explanation lies in the fact that the true south magnetic pole of the earth is actually located in the northern hemisphere, and the true north magnetic pole is in the southern hemisphere.

The geographic poles are the extremes of an imaginary line passing through the centre of gravity of the Earth and about which it revolves. The poles are therefore symmetrically situated with regard to the equator. On the other hand, the magnetic equator does not coincide with the geographical equator (Fig. 7) nor do the magnetic poles coincide with the geographic poles—they are not even diametrically opposite to each other. The true magnetic south pole—that in the northern hemisphere—is 1,400 miles away from the north geographic pole. It was located (in 1831) by Captain James Ross as being in King William Land, Canada, at a point 70° 5′ N. latitude and 96° 43′ W. longtitude.

The position of the true magnetic north pole—that in the southern hemisphere—was also first located by Ross. It was more closely determined by Shackleton's 1909 expedition to the Antarctic as being 72° 25′ S. latitude, and 155° 16′ E. longtitude at a point south of Australia.

It is obvious that as a compass needle points in the direction of the magnetic pole, it does not point actually to the geographic pole. Clearly, the deviation from the true north of a compass in the northern hemisphere will become

more pronounced as the compass is is moved further north. Because of this fact allowance has to be made at any particular place for this "angle of declination", as it is called, so that an exact indication may be obtained as to how far away from true geographic north the compass needle is pointing. The values of the declination of the magnetic needle at different places are known and are shown on the charts, or magnetic maps, to which reference is always made when steering ships by the magnetic compass.

MOTION OF MAGNETIC POLES

The matter is further complicated by the fact that the magnetic poles have a slow motion around the geographic poles, and there is also a daily change in the declination. Declination changes towards the east until about 8 a.m. each day, when it moves westward until about 2 p.m. when it again changes to the east. This oscillation is greatest in mid-summer and least in mid-winter, and it has opposite characteristics in north and south hemispheres. There seem to be changes, too, due to the varying position of the moon, and even the planets are thought to have some effect, according to their varying distances. There are also other changes requiring long periods of time for their completion. Thus in 1580 the declination at London was 11° 15′ E., but the needle gradually moved towards the true geographic north until in 1657 it pointed due north in London. It then moved westwards until in 1800 it had reached 24° 16′ W. In 1936 it was 13° W., and about the year 2000 it will point due north again. These changes are equivalent to a rotation of the Earth's magnetic axis about its geographic axis in a period of about 1,000 years. Why this should be remains one of the mysteries of science.

There is another curious thing about a compass needle. This is the fact that it does not lie in a perfectly horizontal plane for its north end points downwards from the horizontal in the northern hemisphere, and its south end downwards in the southern hemisphere. The angle it makes with the horizontal is called the "angle of dip". The needle being free to move in all directions naturally points in the direction of the Earth's magnetic force. In the northern hemisphere the north magnetic pole is nearer than the south magnetic pole. Its influence is therefore the stronger, thus causing the compass needle to dip towards the north, and vice versa. At the equator where the influences of the two magnetic poles are equal, a compass needle does not dip at all. At a point exactly over either magnetic pole, the compass needle would take up a vertical position if free to do so.

MAGNETIC STORMS

In addition to these changes, there are numerous magnetic disturbances of a non-periodic character. Some are pulsations lasting only for a few seconds or a few minutes, others are of a very irregular type. Large disturbances, known as magnetic storms, have their origin in the Sun and are associated with displays of the aurora in the polar regions and with interruptions to telegraphic communications. They are probably due to the occurrence of electric currents generated in the Earth's crust. These magnetic storms vary over the eleven-year period of the sunspot cycle to which we have already referred, and they are more frequent and of greater intensity when sunspots are most numerous (see Fig. 5, page 11). In these years, too, the magnetic declination and inclination show decided changes.

There are many observatories engaged in the study of magnetic phenomena distributed over the world,

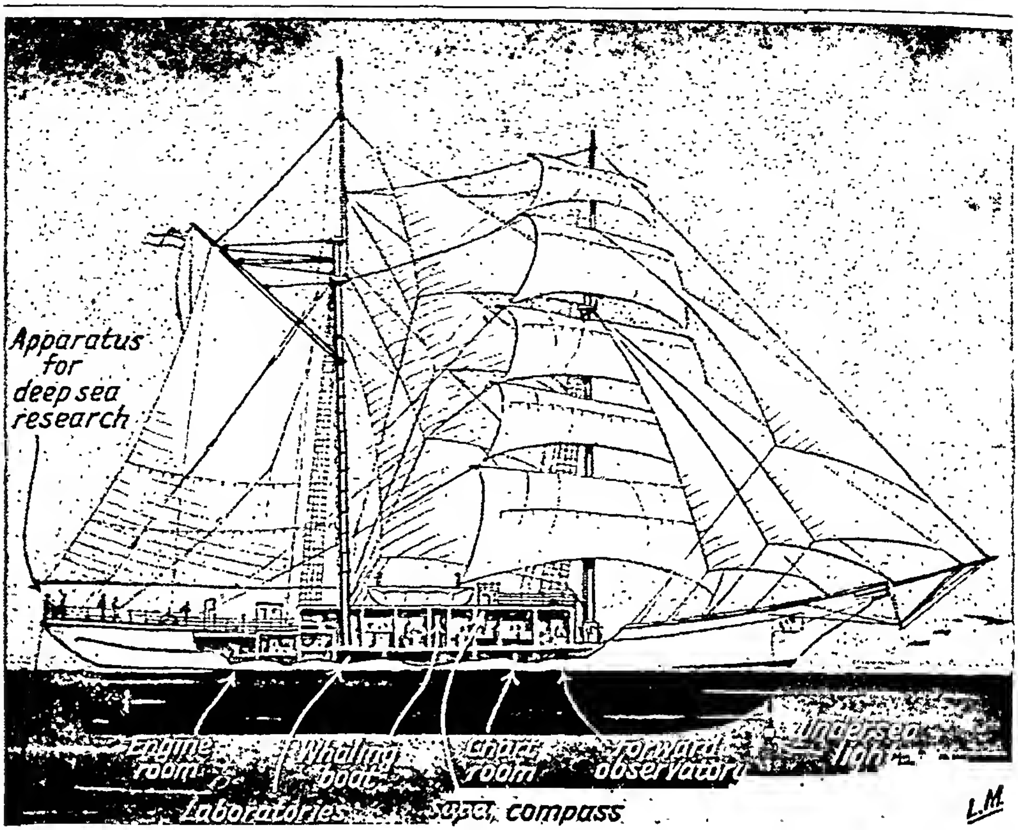


Fig. 8. The new non-magnetic research-ship *Research*, which was constructed by the British Admiralty and launched in 1939. The scientific information it collects will be at the disposal of all.

but as four-fifths of the surface of the Earth consist of water, where observation is equally important, special research vessels are used for ocean study. A new floating observatory, *Research* was launched in 1939 on a quiet reach of the River Dart in Devon (Fig. 8). She replaces the research ship belonging to the Carnegie Institute which was destroyed by fire at Apia, Samoa, in 1929. The vessel is of special design throughout, and particularly in regard to the fittings. The auxiliary machinery consists of three diesel engines for two dynamos, a refrigerator and air compressor, with laboratories or workshops, dark rooms, offices, and record rooms. Although the vessel cruises mostly under sail, she is fitted with an auxiliary heavy-oil motor. Her displacement is 850 tons, and she carries enough fuel to give her a cruising radius of 2,000 miles at a speed of six knots. All the machinery and fittings are made of special non-magnetic alloys. Steel and iron, the chief building materials for ships, are rigidly banned, and members of the crew will not even be allowed to carry a steel penknife. The hull is made of teak, with the framework, girders and fittings of bronze or other non-magnetic alloys. Anchor, cables and all the bolts are of bronze, and even the cooking equipment must have no steel or iron in its composition. The ballast is of lead. There is accommodation for 22 petty officers and men and six officer-scientists and four scientists.

The *Research* is the only non-magnetic vessel in the world. Although built to the order of the British Admiralty, she is an international vessel, since all the

scientific information she collects is freely at the disposal of every country in the world. She will be neutral territory in time of war, and she flies a special non-national ensign. The new floating laboratory winds about the oceans on the longest voyages in history, continuing the work of the *Carnegie* where it was left off when that ship met her end. She is equipped with scientific instruments of great precision, including a marine collimating compass for determining compass-variation at sea, a sea-deflector for determining magnetic intensity, and a marine earth-inductor.

TASK OF THE "RESEARCH"

Among the chief problems to be investigated will be the measurement of electrical pressure in the atmosphere, in which surges occur unexpectedly in all parts of the world; measuring the depth to which cosmic rays from outer space penetrate the ocean; determination of local magnetic disturbances due to the presence of minerals; magnetic storms due to sunspots; magnetic dip and declination; investigation of the perpetual loss of negative electricity and the mystery of its steady replacement; investigation of atmospheric electricity and the ionisation of the air. Finally, there is the investigation of the downward and upward electrical charges, of which the former predominate over land in calm weather and the latter in stormy weather.

This marvellous ship's first cruise across the seven seas will last for two and a half years. Her immediate task is to visit certain positions in the South Indian Ocean and there to re-determine the value of the Earth's magnetism. On the accuracy with which the variations are measured depends to a certain extent the accuracy of navigation with the magnetic compass. Thus the scientific work carried out will be an important step in increasing the safety of navigation for all ships at sea. The data collected will be recorded on Admiralty charts, and copies of these will be available to mariners and scientific research-workers of all nationalities.

In addition to pointing in a north-and-south direction when swinging freely a magnet has the property of attracting certain metals. Not all metals are magnetic, however, some being attracted more than others. Steel and iron are the most easily attracted, whilst nickel, cobalt, and chromium are attracted only very feebly. Copper, lead, gold, and platinum are non-magnetic and cannot be made into magnets. Whilst some metals may be magnetised but do not retain their magnetism permanently, others retain their magnetism indefinitely and are known as permanent magnets.

WHY DO MAGNETS ATTRACT?

How exactly a magnet attracts metals cannot be stated—it is another of the mysteries of science. A very probable explanation, however, is provided by the molecular theory. We have seen already that all matter is made up of molecules—a steel bar is a mass of particles each of which is a tiny magnet with its north and south poles. In unmagnetised steel these molecular magnets are arranged in a haphazard fashion in the bar so that the mutual attraction and repulsion of their north and south poles cancel each other out, as it were. When the bar is magnetised, however, the molecules are re-arranged in an orderly manner. They turn on their axes and tend to assume positions in which they are parallel to one another, with their north poles all pointing in the same direction. This results in the closed magnetic circuits of the unmagnetised bar being altered, giving rise to external magnetism.

The change in position of the mole-

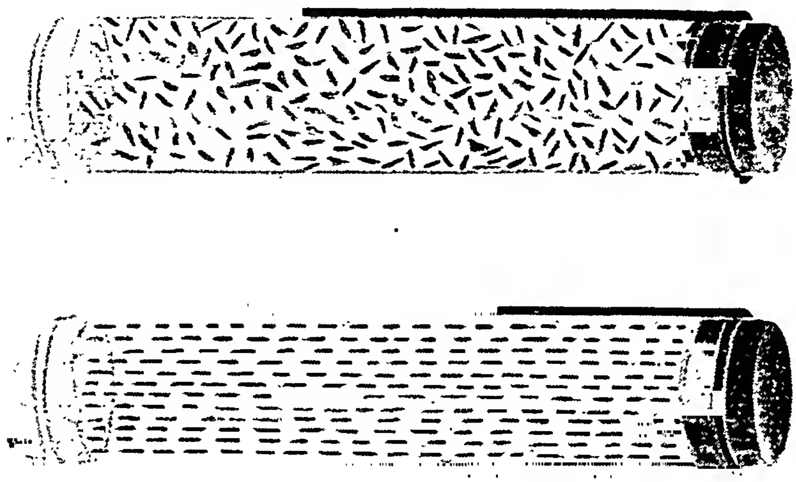


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Fig. 9. An experiment to illustrate the molecular theory of magnetism. When a tube of iron filings (above) is magnetized, the filings all arrange themselves in the same direction (below).

cules when a steel bar is magnetised cannot of course be seen, but we can demonstrate the idea by a simple experiment. A small glass tube is filled with iron filings, and corked at each end (Fig. 9). A freely- suspended unmagnetised needle is then brought near the tube to show that the tube has no marked attraction or repulsion at either end. If we now gently stroke the outside of the tube of filings with a magnet, repeating the process about a dozen times, and moving the magnet always in the same direction—being careful not to shake the tube—we find the filings arrange themselves in an orderly manner (Fig. 9). On testing again with the unmagnetized freely-swinging needle, we now find that one end of the tube definitely attracts the unmagnetised needle. If we shake the tube, so causing the filings to inter-mingle, we at once destroy the magnetism.

According to the molecular theory of magnetism, therefore, the molecules of unmagnetized steel or iron in a bar are irregularly disposed. When the bar is magnetised they are moved on their axes and arranged in a regular manner. When they are completely moved in this way the material is said to be "saturated", and in this condition it cannot be further magnetised no matter how strong a force is employed.

WHY STEEL MAKES GOOD MAGNETS

Now, why does steel make a better magnet than iron? The reason is that the molecules of magnetised steel tend to retain their new positions, whereas nearly all the molecules of soft iron tend to return to their original positions almost as soon as the magnetising force is removed. This is because the friction between the molecules of steel being greater than the friction between the molecules of iron, they cannot easily return to their original positions.

On the other hand, when made into a temporary magnet by passing an electric current around it, soft iron has a greater attractive power than steel when current is flowing. Steel, however, has greater attractive powers when the current is switched off. Actually, when

the current is switched off the iron does remain magnetised very slightly, and this effect is known as "residual magnetism" as against the "retentivity" of the power of steel to retain magnetism. Residual magnetism is of great importance in operating electric generators, for their self-exciting properties depend on this factor.

The magnetic force exerted by a magnet cannot be perceived by our senses but its existence can be demonstrated by the effects it causes, as for instance with iron filings. By sprinkling these on a sheet of paper or thin card, we can trace out the direction of this force and its distribution in the space, or "field", as it is called, that surrounds a magnet. By evenly sprinkling filings on a card and placing a magnet underneath we see that the filings at once take up definite positions when the card is gently tapped (Figs. 10-13). As they are not distributed evenly over the magnet, it is clear that the magnetic force is not the same at all distances, but decreases according to the distance from the magnet. In these experiments we must remember that although the filings on the card show us the action of the magnetic force on a plane surface only, the force acts in all directions from the magnet.

The directions of the magnetic force from a magnet can be ascertained easily by means of a freely swinging needle, such as that of a compass. If a bar magnet be placed on the table and the

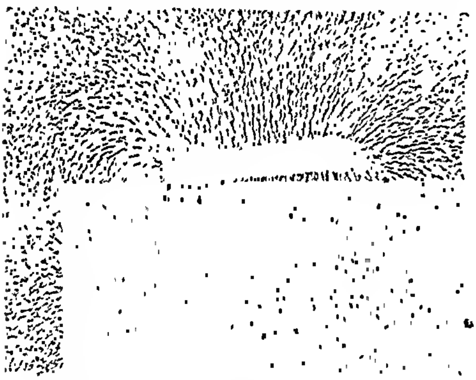


Fig. 10

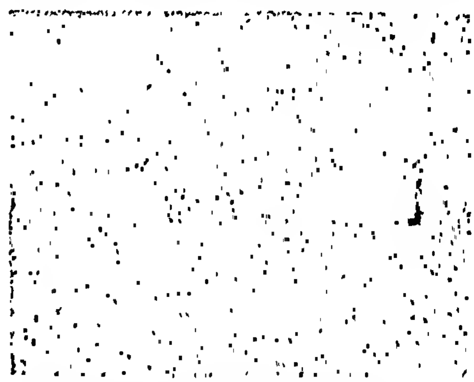


Fig. 11

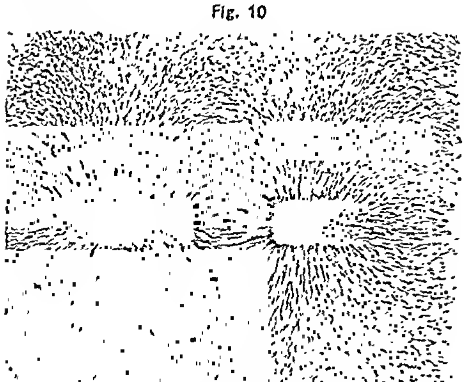


Fig. 12

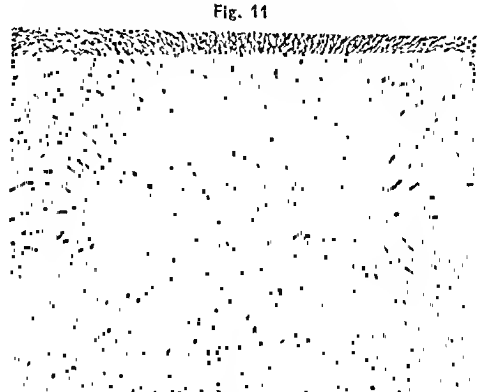


Fig. 13

Lines of force traced in iron filings on paper by variously arranged magnets. Fig. 10. Horseshoe magnet. Fig. 11. Bar magnet. Fig. 12. Opposite poles of two bar magnets. Fig. 13. Similar poles of two bar magnets. Note that unlikes attract each other, and like poles repel.

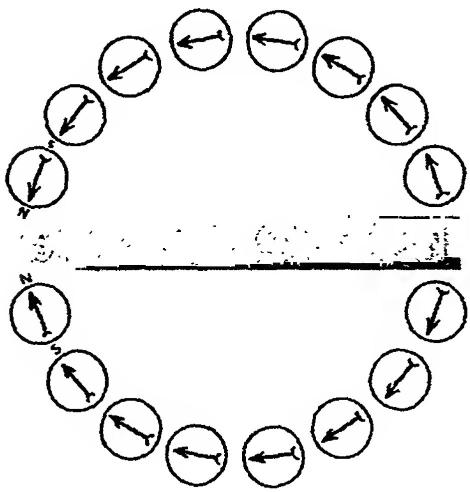


Fig. 14. How the magnetic lines of force which surround a bar magnet may be plotted by means of a small pocket compass.

needle moved around it, from pole to pole, we see that it inclines at an angle that increases as the poles are approached and follows a continuous curve (Fig. 14). By noticing the inclination of the needle it becomes clear that the magnetic force has a definite direction at every point.

The lines on which it acts are called *magnetic lines of force*. These lines of force stream away from each pole of the magnet, those from the north pole passing in curved lines to the south pole, completing the circuit back to the north pole through the magnet itself. Every line has a complete circuit, and it is for this reason that it is impossible to have a magnet with one pole.

HOW LINES OF FORCE BEHAVE

It is interesting to notice, too, that each magnetic line completes its circuit independently of the others and never cuts, crosses, or merges with another line. The lines are much more numerous where they leave the magnet at the north pole and where they re-enter at the south pole. This is due to the fact that steel is a better conductor of these lines of force than the surrounding medium, hence the lines of force are concentrated in the magnet and crowd together at the poles.

These lines of force in a magnet are the principle behind many electrical measuring instruments and electrical devices used in every-day life. Such instruments rely on the fact that the magnetic lines of force always take the path of least resistance. If a piece of iron is suspended so that it is free to move in a magnetic field, it will tend to take up a position in which the greatest number of the lines of force are accommodated through itself. Should the freely-moving body itself be a magnet, it will move in the same direction as those lines of the field in which it is mounted.

A sheet of wood or glass will not alter the deflection of a needle if placed between it and a magnet—in fact, there is no known material that will insulate a body from a magnetic field. Soft iron will serve as a screen, however, conducting the lines of force away from a region. For this reason delicate electrical measuring instruments are sometimes enclosed in heavy cast-iron boxes. To protect a

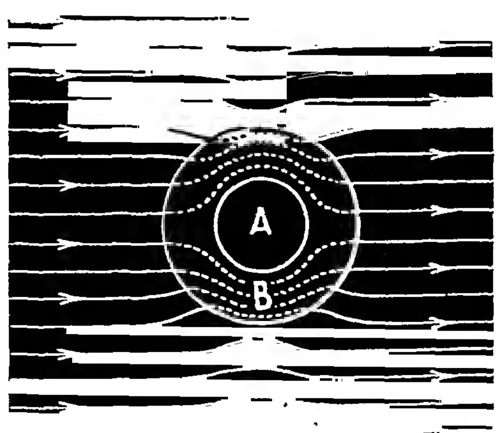


Fig. 15. Showing how an iron tube (B) acts as a magnetic screen, conducting the lines of force from a magnetic field away from the inner cavity (A), leaving it free from interference.

device it is encircled with a soft iron screen and this tends to conduct the lines of force of the field around it, thus leaving the central cavity free (Fig. 15).

As we have seen, the magnetic lines of force extend in all directions from the poles of a magnet. They may be concentrated by attaching soft iron pole-pieces to the poles of the magnet (Fig. 16). Between—but not touching—these pole-pieces another magnetic body may be placed; this body is called the armature. When a coil of wire so placed is rotated, an electric current is produced in it as it cuts through the lines of force of the magnet. This is the principle of the dynamo or generator of electrical current to which we shall refer later.

Fig. 16. A permanent magnet fitted with iron pole pieces, and armature in position.

There is a close connection between magnetism and electricity and many important applications in industry and science depend on it.

An electric current that flows through a circuit acts as a magnet. This can be demonstrated by floating a loop of wire on a cork. It will take up a north and south position, and has north and south poles, and these take each other's places if the direction of the flow of current is reversed.

One of the most important effects of an electric current is its magnetic effect, for it is by means of this that such appliances as the telegraph and the telephone are rendered possible. If a foot or two of insulated wire is wound about fifty times round a piece of iron rod—a poker or a large nail will serve the purpose—and the ends of the wire are connected to a battery or to a generator, the rod or nail will be magnetised as long as the current remains on (Fig. 17). The rod will pick up tacks or pins, but immediately the current is disconnected these are no longer attracted and drop from the rod.

Even the strongest permanent magnet exerts only a small force compared with electro-magnets. This is because the steel of a permanent magnet has a saturation point beyond which it cannot take

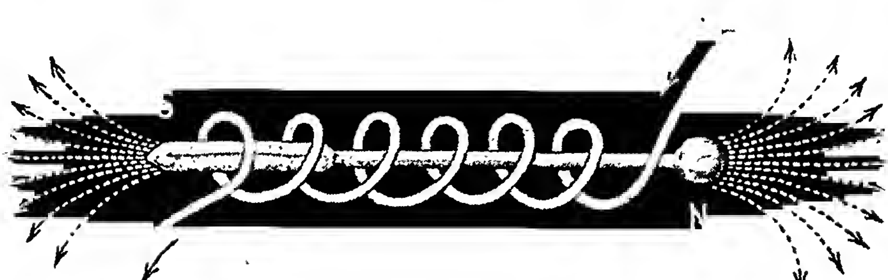


Fig. 17. If a number of turns of insulated wire are wound round an iron or steel bar such as a poker, and a strong current from a battery or generator is passed through the coil, the bar will become magnetized, showing north and south polarity like any other magnet.

up any further magnetism. On the other hand, an electric magnet can be composed of a large number of turns of wire around an iron bar or core. What happens is that the wire has circulating round it an electric field in a continuous series of lines, as though the wire lay in the central axis of a tube. All the lines of force run in the same direction and their combined force even in one layer of wire is considerable. With additional layers wound closely together this force can be made very much greater, particularly when a heavy current is used—and currents of up to 5,000 or more amperes are sometimes used, although only in the laboratory.

ELECTRO-MAGNETS IN INDUSTRY

Electro-magnets have many applications in industry, particularly as solenoids for operating railway brakes, electric signals and so on. Large electro-magnets used for lifting metal are attached to a crane and lowered to the object to be picked up. The current is switched on, the magnet attracts the metal, is lifted and moved by the crane to the place required, when the current is switched off and the metal dropped into position. Voltmeters and ammeters use the same principle for measuring current—one very sensitive type of moving-coil galvanometer has a tiny mirror carried on a fine coil that hangs between the poles of a magnet. The mirror reflects a spot of light on to a revolving drum of sensitised paper or photographic film, and such a coil is so sensitive that it will detect a current of as low as one ten-thousand millionth part of an ampere.

We have seen that surrounding a magnet and surrounding an electric current there is a magnetic field in which pieces of iron or steel become magnets. We have seen, too, that the Earth possesses a magnetic field, for a freely-suspended magnet will set itself in a given direction. Now, we should expect that a piece of iron would be magnetised if placed north and south in the Earth's magnetic field, and in fact this can happen. A piece of soft iron will be magnetised fairly quickly—steel takes longer, though the process is assisted by hammering—the end of the bar facing north becoming the north magnetic pole of the magnet. A vertical bar of iron becomes magnetised in a similar way, in which case the lower end becomes the north magnetic pole if the bar is in the northern hemisphere, and the upper end the north pole if the bar is in the southern hemisphere. It is for this reason that iron pillars and railings become magnetised. When so magnetised, the iron and steel used in the construction of ships produces a disturbing effect on the ship's compass. In some cases it may affect the needle by as much as 20°. To overcome this difficulty, corrections, often very complicated, have to be applied. These generally take the form of sets of steel magnets placed at right angles to each other, their centres being under the compass needle. These cause counter-forces in soft iron spheres, placed one on each side of the compass, compensating for the magnetism of the ship's hull.

THE EARTH A HUGE MAGNET

Why does the Earth behave as a magnet? It has been suggested that the Earth's magnetism is due to the presence of magnetic matter within the Earth, but this theory has not been accepted for it does not explain everything. We might suppose that the Earth's interior consists largely of iron, for we know its density is high. We have already seen that the rocks at the Earth's surface are about $2\frac{1}{2}$ times as heavy as water, whereas the Earth as a whole is over 5 times as heavy as a globe

of water of the same size would be; iron has a density nearly eight times that of water. The objection to this suggestion is that the temperature of the Earth's interior must be very high, for reasons we have already explained. Now iron loses its magnetism with heat, susceptibility vanishing abruptly when the temperature reaches 800° C.—known as the "critical temperature". Evidently some important molecular change takes place in the iron at this temperature, for its physical properties also undergo a marked change at or about 800° C. Thus, we can scarcely suppose that the huge mass of iron in the Earth's interior can be in a magnetic state, despite the fact that one of the mysteries of science is how iron would behave under the enormous pressures to which it is subjected in the Earth's interior. As we have seen, these may amount to as much as 22,000 tons to the square inch.

THE GIANT POWER OF MAGNETISM

This man is being held up solely by the attraction exercised by the electro-magnet for the nails in his boots.

A more probable explanation is that the Earth is a huge electro-magnet, the magnetising currents being caused by streams of electrified particles that circulate in the higher atmosphere. According to this theory, daily variations would be caused by atmospheric oscillations of the same type as those that cause daily variations in atmospheric pressure and, therefore, in the weather.

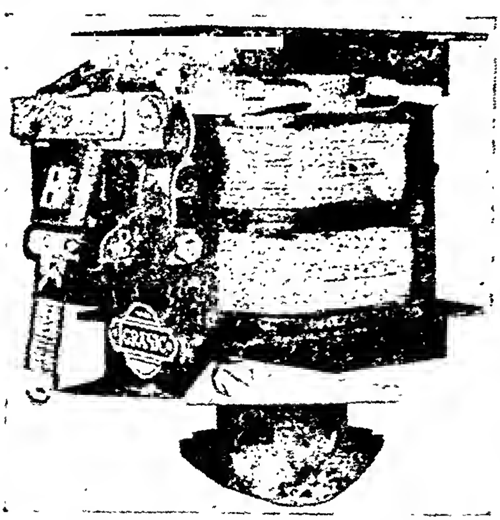
Yet another theory is based on the fact that electrical charges are escaping from the Earth into space. The source of these electrical charges has not hitherto been discovered and it has been suggested that the positive charges o electricity that form the nuclei of th atoms in the Earth's interior are bein converted into energy, and that th negative electrons are escaping an moving through the Earth's crus passing through the atmosphere in

space. Thus, the Earth is continually disseminating electrical charges into space, and we know from simple laboratory experiments that a rotating electric charge causes a magnetic field.

This last theory is comprehensive, accounting satisfactorily for everything, including the source of the Earth's internal heat. Theoretically the Sun must also be a magnet—its material, we know, is similar to that of the Earth; it, too, is hot; and it is rotating. The spectroscope shows that there is indeed an enormous magnetic field around the Sun. At the Sun's poles the magnetism is over 100 times its value on the Earth, and in and around the sunspots, some 40 times, thus confirming the theory in regard to the Earth.

When a soft iron bar is brought near to a magnet it acquires temporary magnetic properties—for example, it will attract iron filings (Fig. 18), and show polarity, or attraction and repulsion to the opposite or similar poles of another magnet.

The degree of magnetic power it acquires depends on the strength of the magnet and on its distance from the magnet, being greatest when in actual contact. In these circumstances the



Courtesy of Igranic Co. Ltd.
A large solenoid for electrical control.

Fig. 18. A piece of iron placed near a bar magnet becomes temporarily magnetised.

iron is said to be magnetised by induction. If steel is used instead of soft iron, the inductive effect only becomes manifest after the lapse of a certain time. On the other hand, when the magnet is removed the steel bar does not immediately lose its induced magnetism, whereas the iron loses it immediately the magnet is withdrawn.

WHY STEEL RETAINS MAGNETISM

We may ask why this happens. The answer to the question is that every atom of a piece of iron is a separate magnet that is capable of turning on its axis. When a magnet is brought near an iron bar, all the atoms turn so that the north poles point in the same direction, and the iron bar itself possesses temporary magnetic powers. In the case of steel, however, there is this difference—that between the atoms of iron are atoms of carbon, and they tend to prevent the iron atoms from swinging with their poles in line. Continued application of a magnet to a steel bar overcomes this resistance, however, and the enemy becomes the friend, for the carbon atoms prevent the iron atoms from swinging back. Thus, the molecules remain permanently with their poles pointing in the same direction and the steel remains a permanent magnet.

Now let us see how each atom of iron can be a magnet. The answer is not far to seek. We know that an electric current is simply a stream of electrons flowing in a circuit from one terminal of a battery to the other and through the battery, so forming a continuous flow. We have seen, too, that atoms are

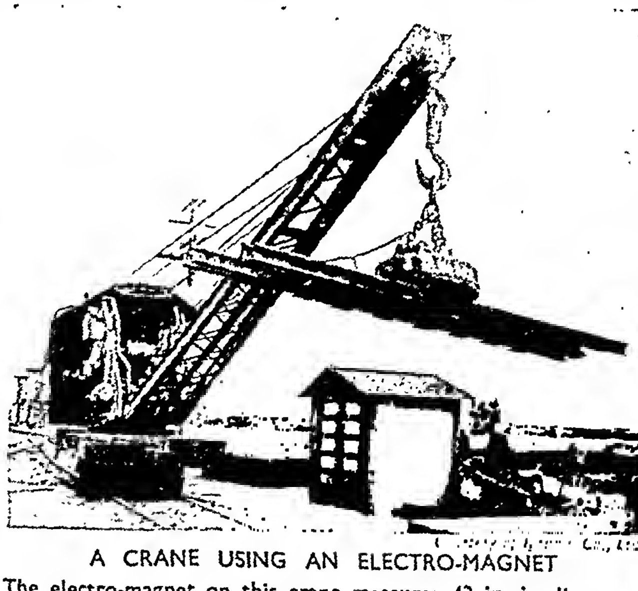
believed to consist of electrons that are revolving in tiny orbits, so that in them we have the equivalent of an electric current and every atom should therefore be a magnet. Something must be wrong with this, however, for we know that not every atom is a magnet—we cannot magnetise brass or copper. Why? Because the non-magnetic substances are composed of atoms that have electrons revolving in one direction and equal in number to the electrons that revolve in the opposite direction—they pair off, as it were, with the result that their magnetic forces cancel each other out. The atoms of iron, on the other hand, have electrons that do not pair off, so that each atom resembles a minute electrical circuit capable of giving out a magnetic force. When magnetised, all these minute electrical circuits set themselves in the same direction—their forces are combined and manifest themselves as magnetism.

The question of how far different kinds of iron and steel become magnetised when placed in a given magnetic field is one of great practical importance. Most of the common metals are not attracted by magnets. Curious exceptions are certain alloys, which although made of non-magnetic metals themselves may be magnetic. One such, for example, discovered by Hensler in 1903, is composed of 61 per cent. of copper, 24 per cent. manganese, and 15 per cent. aluminium—all practically non-magnetic separately, but strongly magnetic as an alloy.

Exactly as there are so-called lines of force around a magnet, so there are lines of force around a wire through which an electric current is passing. These lines of force can be shown by passing a wire through a card so that it stands perpendicular to the card. If iron filings are now sprinkled on the card and the ends of the wire connected to a battery, the filings will arrange themselves in concentric circles with the wire as a centre (Fig. 19). They do not begin at a north pole and pass to a south pole as in the case of a magnet, for there are no poles in a wire. Each line of force is a circle, without end or beginning.

LINES OF FORCE ROUND A WIRE

A wire carrying a current will deflect a compass needle placed near it. It will be seen that the movement of the poles of the compass needle is at right angles to the wire carrying the current. We can also determine the direction of the flow of the current from the battery. Thus, it may be shown that the current leaves the battery by the positive terminal and returns to it by the negative terminal,



A CRANE USING AN ELECTRO-MAGNET

The electro-magnet on this crane measures 43 in. in diameter. Such cranes are particularly useful for railway assembly work as they eliminate a great amount of handling of the loads.

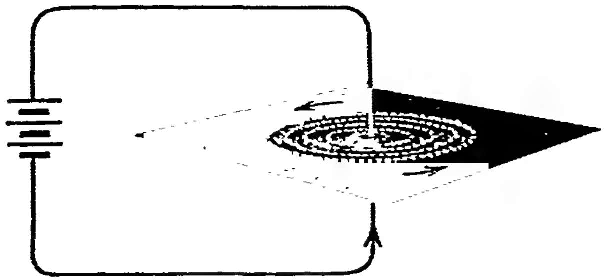


Fig. 19. Showing that magnetic lines of force exist round a wire through which an electric current is passing. (See page 329.)

exactly as the lines of force left the bar magnet by the north pole and returned by the south pole.

There is, of course, a close connection between magnetism and electricity and the study of the one subject necessarily goes hand-in-hand with that of the other. In times to come, no doubt the present will be known as the Electrical Age, for year by year electricity is playing an increasingly important part in our lives, increasing the amenities of modern civilisation. So universally is electricity now used, and so familiar has the phenomena associated with its application become, that its existence is taken for granted in much the same way as is the air we breathe.

Let us see, now, if we can learn what electricity is and how it can be used.

First, we must realise that it is not possible to define electricity in the same manner as one would define the power exerted by the rapid burning of an inflammable mixture, such as petrol, or by expanding steam. It may be said to exist as one of the many phenomena of nature that are only made manifest when following certain natural laws. These laws are manifest, irrespective of whether they are fulfilled or reproduced naturally as in the case of lightning, or whether by mechanical or chemical means as with the dynamo and battery. The force we term electricity is present wherever matter exists.

In our consideration of the question "What is Electricity?" it will be necessary for us to traverse again some of the ground already covered in our chapter dealing with the constitution of matter. As we saw there, matter is defined as anything that occupies space, whether solid, liquid, or even gaseous substances that are invisible.

The electronic theory of matter, which was put forward at the beginning of the present century, gives us a basis for the definition of the force electricity. As we have already seen, it is considered that each atom is made up of a nucleus, consisting of a minute amount of positive electricity and a number of other particles that are attracted to this nucleus consisting of negative electricity. The negatively-charged particles, or electrons, are considered to be in a state of constant movement about the nucleus. According to the rapidity and extent of this movement, so is the body of which they form the atoms given its character—solid, liquid, or gas—and degree of heat.

ATTRACTION BETWEEN CHARGES

This theory also accounts for the fact that particles containing different charges of electricity have a natural attraction for each other, and similarly charged particles have a natural repulsion. It is supposed that electrons are the constituents of all atoms of matter and that they are identical, whatever the source from what they are obtained. Also, by various natural and artificial means, electrons can be made to move from one atom to another.

By so removing them a body will have

a deficiency of electrons, or negative electricity, and an excess of positive electricity. Where electrons are transferred to a body, it will have an excess of negative electricity. In such cases the bodies are said to be negatively or positively charged with electricity.

STATIC ELECTRICITY

These conditions are readily shown by the familiar experiment of rubbing a glass rod with a piece of silk. This produces a static or stationary charge of electricity on the surface of the rod, enabling it to attract light articles, such as silk threads, small pieces of paper, etc. (Fig. 20). This power of attraction was known to the ancient Greeks and Romans, who demonstrated it by rubbing amber. The Greek word for amber was *elektron* and it is from this that we derive our word "electricity". Thales of Miletus, born about 640 B.C., was the first to study the subject, but after his time it seems to have been forgotten until Gilbert, Queen Elizabeth's physican, took it up about the end of the 16th century.

The process of rubbing a glass rod transfers electrons from the rod to the silk, and by their flow through one's hand and body to the Earth, they leave the atoms in the surface of the rod with an excess of positive electricity. If the material with which the rod is rubbed is insulated from Earth to prevent the escape of the excess electrons, it will be found to have an excess of negative electricity and is then said to be negatively charged. On the other hand, if a rod of amber, sealing wax, or vulcanite is treated in a similar manner, electrons are transferred from the silk to the rod, so that the rod becomes negatively charged and the silk positively charged.

This can also be demonstrated by a phenomenon that no doubt everyone has noticed when combing his hair. A light crackling is heard, due to the transference of electrons between the hair and the comb. It will even be found that if the comb is made of one of the popular plastic materials, it will attract very light articles. The light stroking of the hair of an animal such as a cat will produce the same effect, and in a darkened room there will be seen faint bluish sparks at the ends of the hairs as the hand passes over them, indicating the passage of the electrons.

All natural states are states of equilibrium. Therefore, if two negatively-charged bodies, or two positively-charged bodies, are brought into contact they tend to repel each other, for there is no tendency for the electrons to move from one body to another as each has a similar excess or deficiency. If bodies having dissimilar charges are brought together, however, they attract each other. The electrons flow from the body with an excess to the body that has a deficiency, until each has an equal amount and they are in equilibrium.

WHAT DISCHARGING MEANS

When electrons flow in this manner the electrified bodies discharge. When the flow ceases and the bodies are in equilibrium they are said to have been discharged.

The form of electricity we have so far considered is known as static electricity,

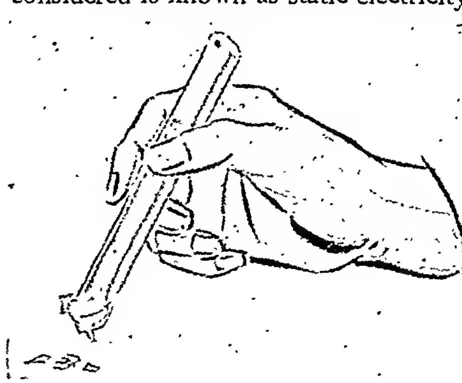


Fig. 20. Sealing wax or glass rubbed vigorously with silk attracts small pieces of paper.

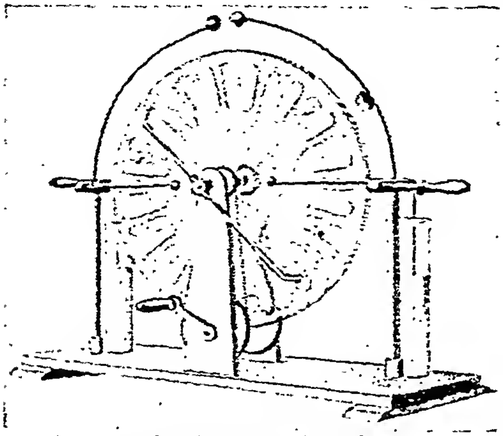


Fig. 21. A Wimshurst machine for producing charges of static electricity.

or electricity at rest. Static electricity is of little interest except for experimental purposes, for it cannot be made to do useful work. As we have seen, it can be made to give a power of attraction to certain things, such as a pipe mouthpiece or a stick of sealing wax, so that it will attract small pieces of paper, tobacco ash, or pith, in a manner similar to that in which a magnet attracts tacks.

EARLY ELECTRICAL DISCOVERIES

After Gilbert published his *De Magnete* many experimenters investigated static electricity. They soon realised the necessity of finding some means of providing larger charges than could be obtained by rubbing glass rods with silk and they devised machines to carry out the rubbing processes on a larger scale. The first of these machines was constructed by Otto von Guericke (1602–86) of Magdeburg. It consisted of a globe of sulphur mounted on a rod and excited by the application of a cloth. Later, Sir Isaac Newton used a glass globe instead of sulphur, and leather pads as a source of friction. These early machines were followed by others in which the essential feature was some mechanical arrangement for rubbing glass cylinders against specially prepared cushions, and from this fact they became known as friction machines. Later these friction machines were superseded by "influence" machines, one of the best known of which was designed by James Wimshurst about 1878 (Fig. 21). In it glass or ebonite plates are caused to rotate rapidly, brass rods collecting the current through combs and becoming so highly charged that sparks pass between them if they are brought close together.

WHAT IS LIGHTNING?

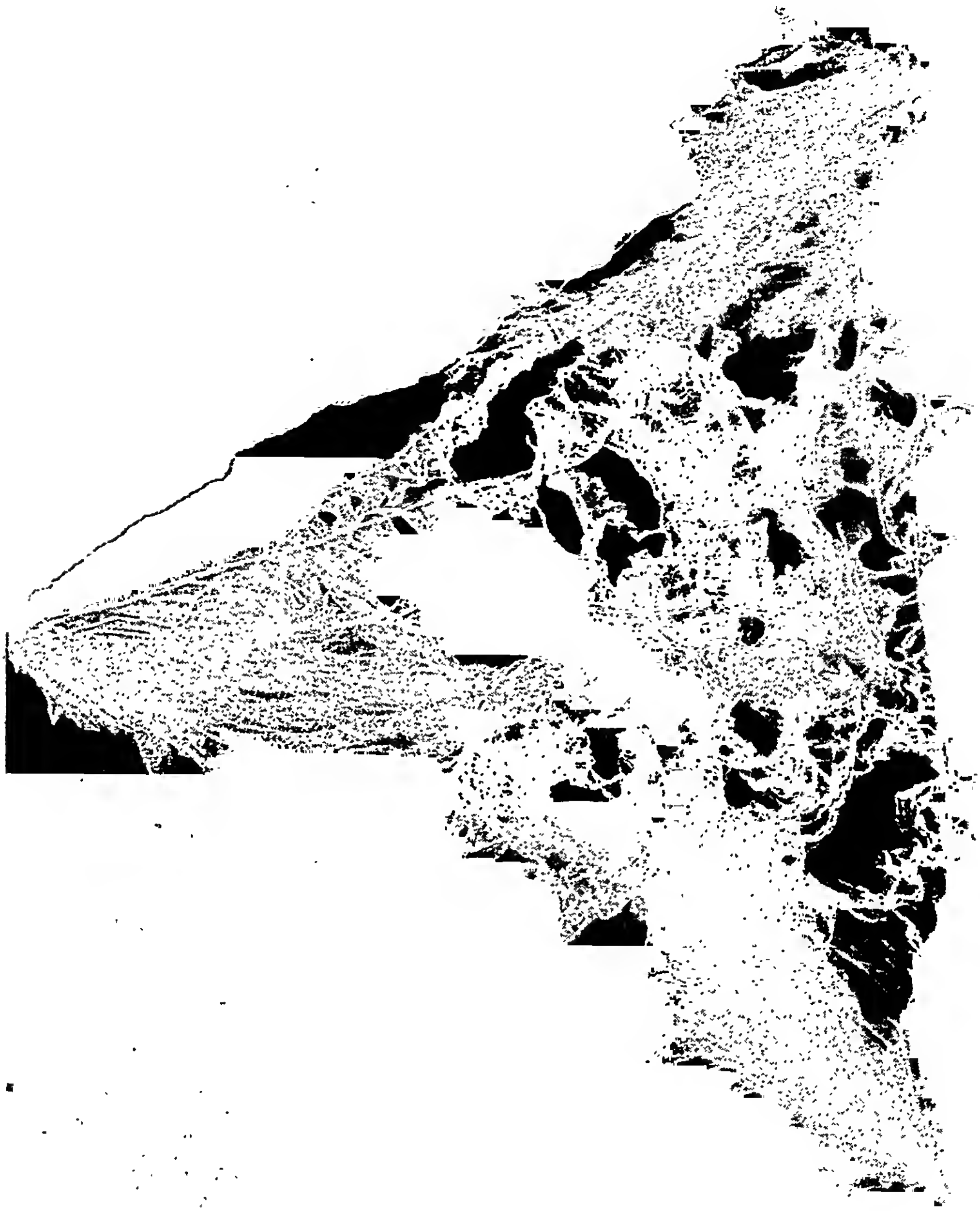
There is a striking resemblance between these sparks and lightning, and in fact the sparks are merely miniature lightning-flashes. The charges on the rods are prevented from passing by the intervening air gap, for air is a non-conductor of electricity. As the charges increase in strength they reach a degree at which the electricity is strong enough to overcome the resistance of the air, and a brilliant spark results, the particles of air being rendered incandescent. Benjamin Franklin was the first to show that lightning is simply a huge electric spark. In 1782, he flew his historic kite in Philadelphia and drew electric sparks from the kite string.

Lightning is simply a gigantic spark between the Earth and a cloud, or between two clouds. It occurs when opposite charges of electricity become strong enough to overcome the resistance of the intervening air. Forked lightning is due to the discharge taking the path of least resistance through the air. Sheet or "summer" lightning is merely the reflection from the clouds of forked lightning at a distance. In this case the distance is so great that the thunder accompanying the discharge generally is not heard. A flash of lightning may be several miles in length, the largest on record being about ten miles.

Thunder is due to the expansion of the heated air along the track of the flash, followed by a sudden rush of

MILLION VOLT ARTIFICIAL LIGHTNING

The physicist can produce "lightning" in the laboratory, as this picture of a 1,000,000 volt spark crossing a wide gap shows. Lightning is merely a spark between two clouds, or one cloud and the Earth, which occurs when high charges of static electricity overcome the resistance of the air.



A NINE-FOOT LACE-LIKE SPARK

This photograph of a 1,000,000 volt nine-foot three-phase spark shows clearly how the line of a spark moves about in the air, finding the path of least resistance.

air into the vacuum formed thereby.

Up to now, then, we have been dealing only with static electricity which is of no practical use. The electricity we use in ordinary life is known as current electricity, which, as the name implies, is electricity in motion.

An electric current may be defined as a drift or flow of electrons or negative electricity from one atom to another,

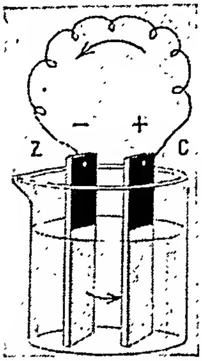


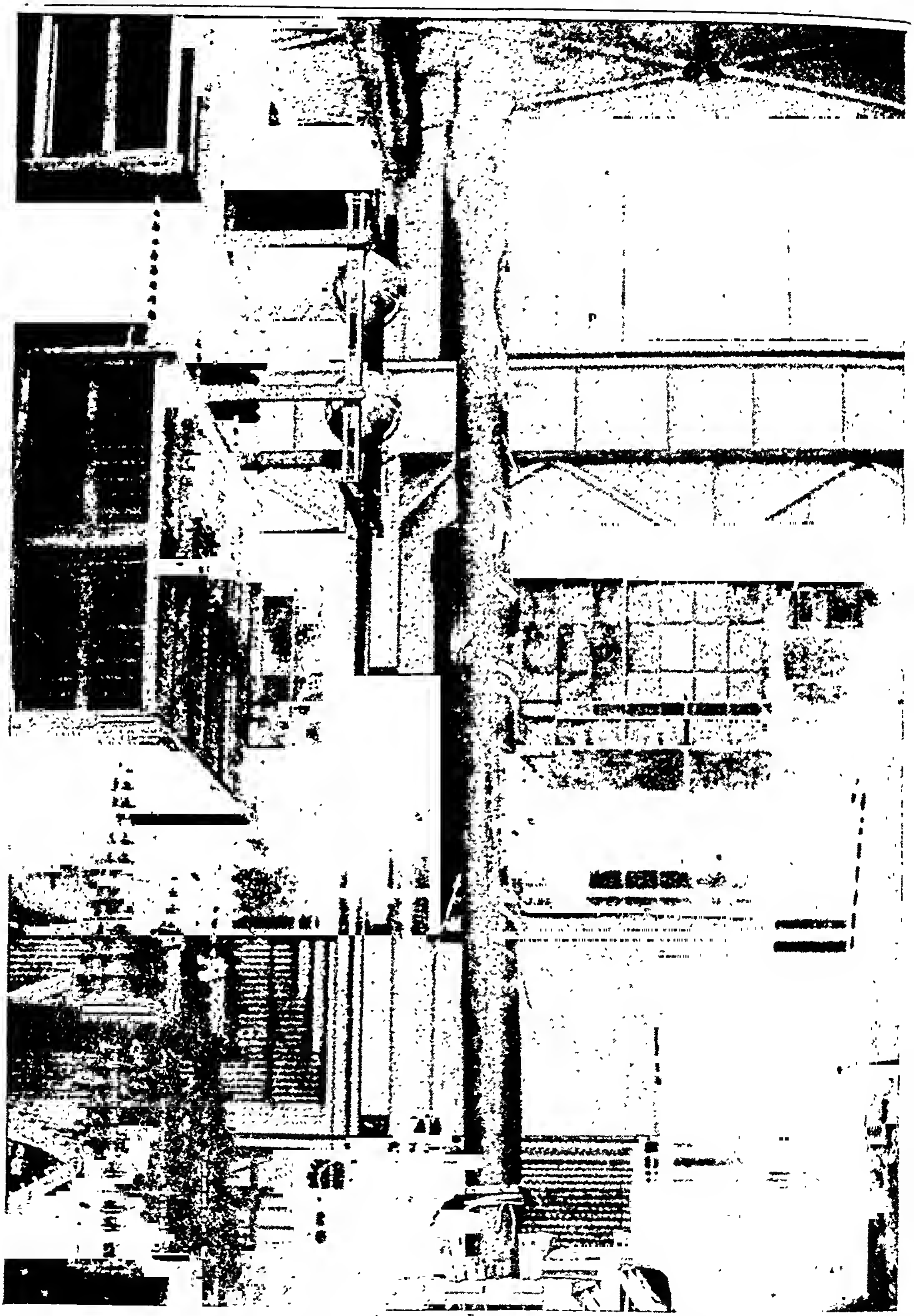
Fig. 22. A Voltaic cell. (See text.)

induced either by natural or artificial means.

When a current is made to flow through a wire this is actually the drift of the negative particles of electricity from atom to atom. Although we think of electricity as travelling so fast as to appear almost instantaneous, the rate of progress is actually very slow. The electrons drift or flow from atom to atom at a rate of possibly only a few yards per hour. However, as previously described, two electrons, or particles of negative electricity, being of like charge, repel each other, so that the electrons are displaced or repelled almost simultaneously in each atom throughout the whole length of the wire, giving an apparently instantaneous effect at a distance.

Alessandro Volta, Professor of Physics at Padua, found (in 1796) that electricity could be produced by bringing two dissimilar metals into contact. He found that when copper and iron were placed in contact one became positively-charged and the other negatively. By alternatively placing a number of discs of these metals and insulating them from each other with pieces of flannel, he was able to obtain a continuous supply of electricity, which renewed itself as quickly as it was used. He found that the best results were obtained when the metals were placed in a vessel that contained dilute acid, and his arrangement is known as the Voltaic cell. It consists of a glass jar containing dilute sulphuric acid, in which hangs a plate of zinc and a plate of copper (Fig. 22). When the plates are connected by a wire, a current of electricity flows along the wire from the copper plate (the positive) to the zinc (the negative) and from the zinc to the copper through the liquid in the cell


Nature releases her electrical forces in a gigantic flash of lightning.



THREE MILLION VOLTS SPLIT A TELEGRAPH POLE.
What happens when lightning strikes a telegraph pole? This picture shows a 20 ft. timber being split by an artificial spark of over 3,000,000 volts.

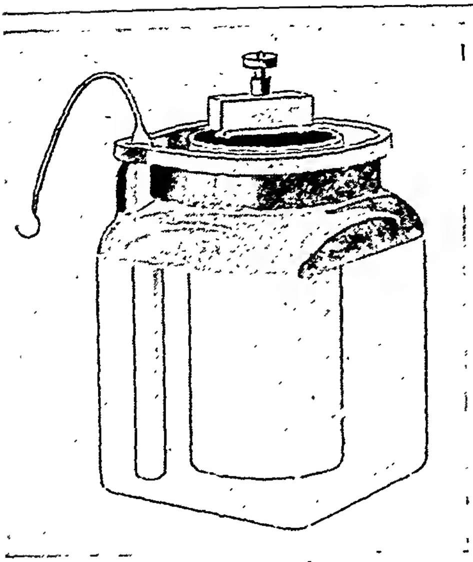


Fig. 23. A Leclanché cell.

so forming what is known as " a circuit." If the circuit is broken by disconnecting the wire, the current ceases to flow and the cell is then at rest. By this means, therefore, chemical energy is converted into electrical energy.

PRIMARY CELLS

The voltaic cell was found to be inefficient and it was subsequently superseded by improved cells. Of these, the best known is the Leclanché, consisting of a glass jar filled with a solution of sal-ammoniac in which is placed a rod of zinc (Fig. 23). The chemical action that takes place whilst the current is flowing results in the wasting of zinc. Actually, when the cell is at rest, chemical action continues to a certain extent owing to the impurities contained in commercial zinc, and the rod wastes away, but this can be obviated by coating—or amalgamating—the rod with mercury.

Also immersed in the solution is a porous pot containing a plate of carbon, around which is packed a mixture of crushed carbon and manganese dioxide. The carbon provides the positive current, the zinc rod the negative. Leclanché cells are used extensively where current is required occasionally and for short periods, as for such purposes as ringing house bells.

A modified form of the Leclanché cell is the so-called "dry battery". Actually these batteries are not dry, for if they were there could be no flow of current. In a dry battery the zinc rod is replaced by the containing vessel, and the liquid by a moist paste that surrounds a carbon rod in the centre of the cell (Fig. 24). The whole cell is sealed at the top and placed inside a closely fitting tube. Such dry batteries are in use for all manner of purposes from flash lamps to radio receivers, their great advantage being the ease with which they can be carried about and placed in any position.

Voltaic cells, Leclanché cells, and other similar cells, as well as dry batteries, are known as primary cells. They produce electric current from chemical action, converting chemical energy into electrical energy.

Such cells and batteries are not capable of providing the electrical power necessary to do the world's work. For this power we rely on the dynamo or electrical generator.

In 1819, H. C. Oersted, Professor of Physics in the University of Copenhagen, discovered that iron filings will cling to a wire through which a current is flowing and that when the current is stopped they fall off. This discovery established the fact that during the passage of electric current the wire becomes a magnet, and that it loses its magnetism when the current is switched off.

In 1831, Michael Faraday, interested in Oersted's discovery that magnetism could be produced by an electric current, became convinced that it should be possible to produce the reverse effect and make magnetism produce electricity.

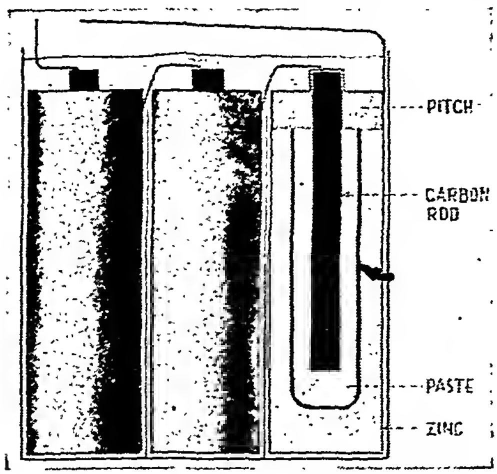


Fig. 24. Construction of a simple flash-lamp battery. One cell is shown in section.

He found that if a magnet is moved towards or away from a coil of wire, or if the wire be moved to or from a magnet, an electric current is induced.

PRINCIPLES OF THE DYNAMO

Faraday's discovery established the relationship between the lodestone and current electricity, and showed the relationship between electricity, magnetism, and motion. It made clear, too, that electrified bodies in motion produce magnetic fields around themselves, and that a magnet in motion creates a current of electricity in conductors that are close to it. These discoveries are the basic principles of the dynamo, the most familiar electricity-producing machine. No matter whether this is a small machine—such as a dynamo for attaching to a bicycle to light its lamp —or whether it is a very large and powerful one for providing a town with light, heat, and power, the principles are the same.

As we have seen, magnetism may be considered as a force of attraction that flows between two points in a manner similar to electricity. Instead of being termed positive and negative, these points are called north and south poles.

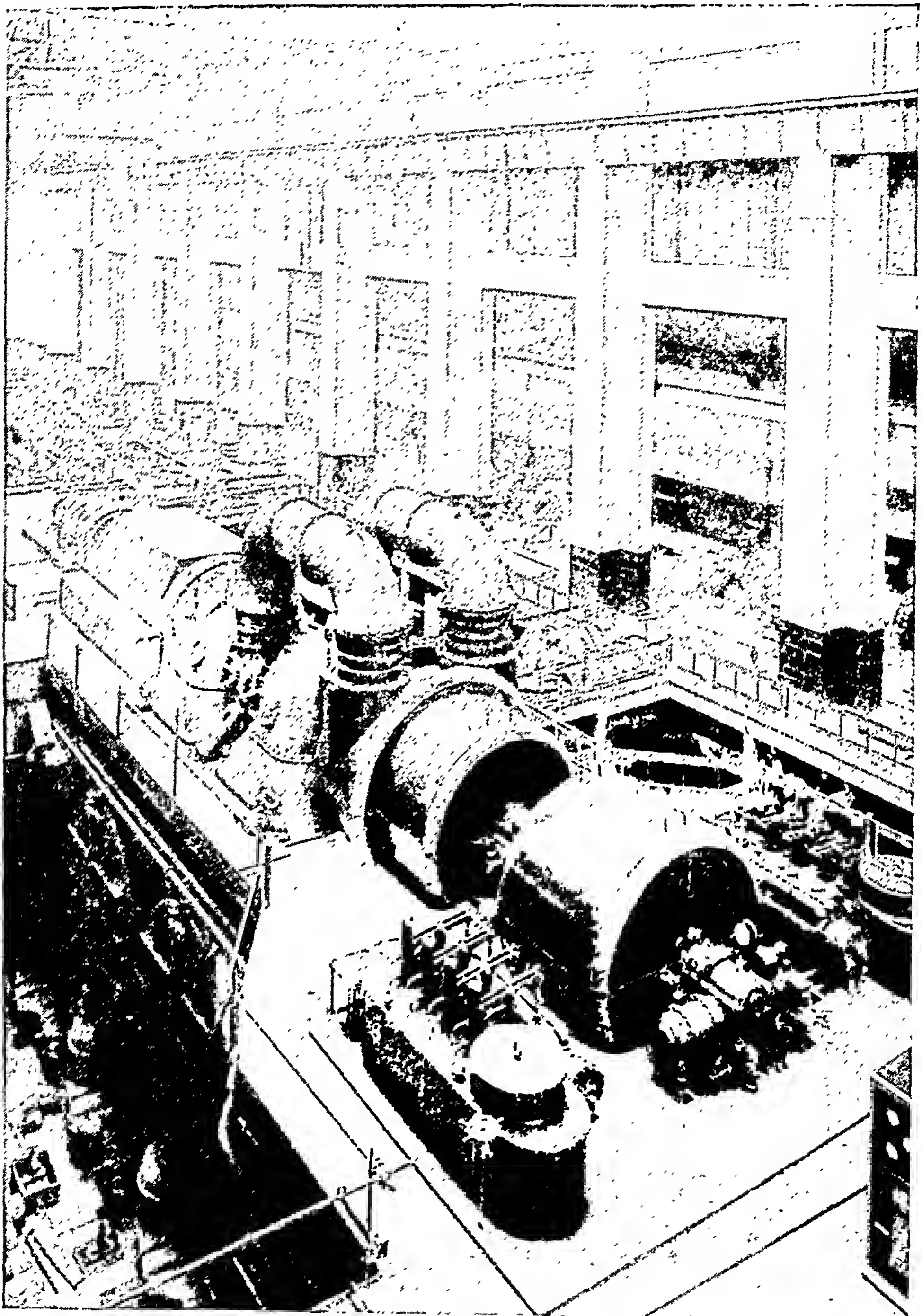
We have also explained that magnetism does not depend on a conductor such as a wire to permit it to flow from pole to pole, but is capable of existing in space. It cannot be insulated, or prevented from flowing, as can an electric current. For convenience, this flow, which is referred to as "lines of force", is considered to flow from a north pole to a south pole.

The movements of electrons that form an electric current may be affected by either natural or artificial means. In the dynamo we have an example of the employment of both these means.

If a loop of a coil of wire is placed between the poles of a magnet and remains at rest, the flow of magnetism has no effect in causing a flow of electrons or electric current. On the other hand, if relative movement is made to occur between the wire and the lines of magnetic force, movement of the electrons takes place and an electric current is said to flow. A current caused in this manner is said to be induced, as there is no mechanical or electrical connection between the magnet and the wire.

This movement has to be made in accordance with certain natural laws, however. First, to obtain the maximum effect, the lines of magnetic force must be moved across at right angles to their flow by the wire loop or conductor. Secondly, as this angle of movement is altered, the current induced in the conductor decreases until if the conductor moves parallel with the lines of magnetic force, no current is induced.

A further natural law controls the direction of the current flow, so that when the conductor is moved across the lines of magnetic force in one direction, the flow of current occurs in a certain direction in the conductor. When the lines of force are moved across in the opposite direction, the flow of current is reversed. This can be shown



POWER FOR HOME AND FACTORY

A 67,200 kilowatt turbo-alternator at Battersea Power Station. Giant generators of this type supply Britain with power and light, yet in principle they are the same as the tiny dynamo on a bicycle.

by the extremely simple experiment of connecting the two ends of a wire loop to a sensitive current-measuring instrument, such as a galvanometer, and passing the loop in the manner described above between the two arms of a horseshoe type permanent magnet (Fig. 25). When the loop is moved in one direction the galvanometer needle will be seen to swing in one direction, but when the movement of the loop is reversed the needle will swing in the precisely opposite direction.

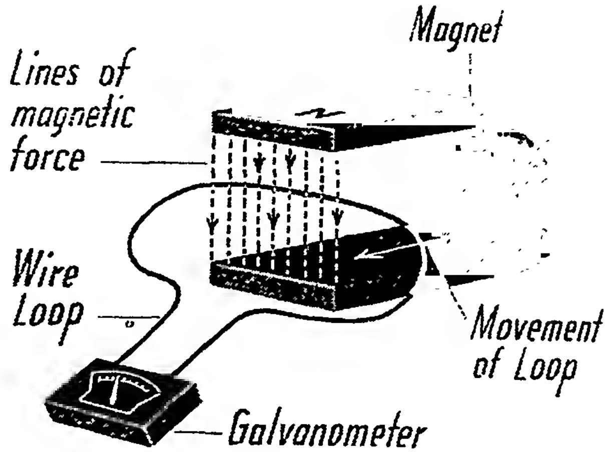


Fig. 25. Illustrating the principle of induced current.

From this principle of operation it will be seen that means would have to be provided to enable the coil of wire repeatedly to cut across the magnetic lines of force. As the simplest of all mechanical motions is that of rotation, it follows that the whole of the coil should be situated between the poles of the magnet. These should be rotated about an axis that will permit the loop of the coil to cut the lines of force at right angles to their flow. If the current now be picked up from the coil whilst it is rotating, we have the dynamo in its simplest form (Fig. 26).

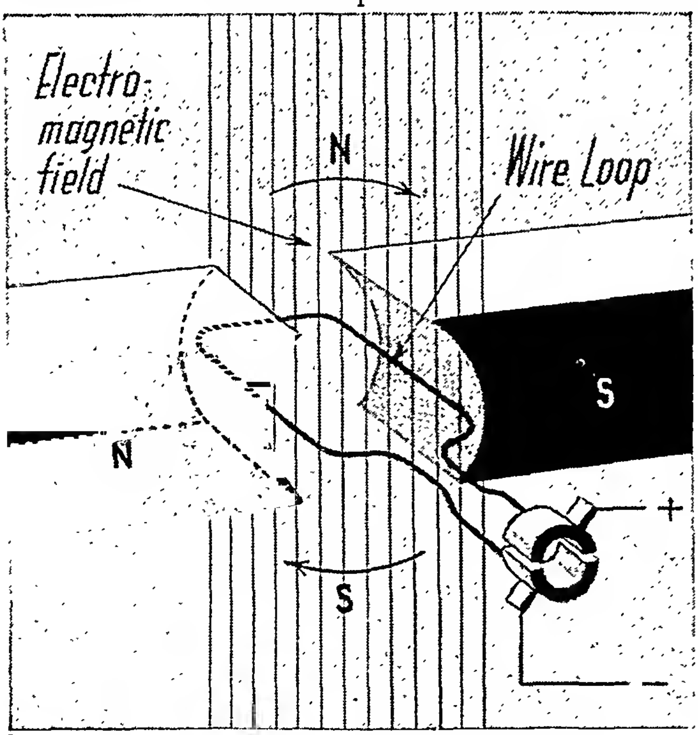
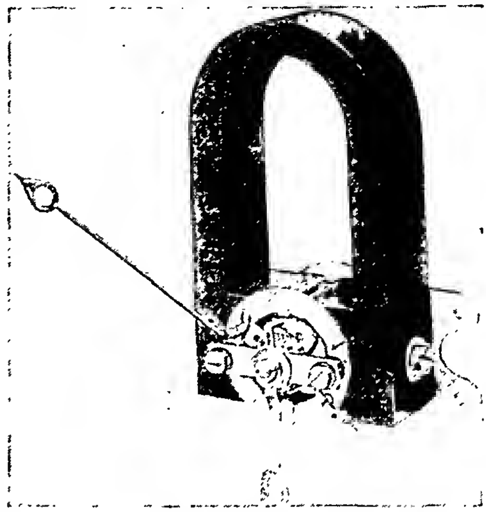


Fig. 26. Magnetic field through loop attracted by permanent field.

The terms "direct current" and "alternating current" are often heard as applied to dynamos. Fundamentally, all dynamos are of the alternating type and it is only by their mechanical construction that they are able to produce direct or alternating current as required by the designer. Let us see why this is so.

When the wire coil is rotated in the manner described above and is cutting across the lines

of magnetic force at right angles to their flow, a current is generated in the wire loop. This current flows in a certain direction, according to the direction of rotation as shown in Fig. 27. If we consider the side of the wire loop adjacent to the north pole of the magnet, we see that by rotating the loop in a clockwise direction the flow of induced current, obeying the natural laws, also flows in a clockwise direction in the loop as shown in the diagram. If the two ends of the loop are connected to two metal collector rings, which rotate with the wire loop and permit sliding contacts to collect the current from them as it is induced, a voltmeter, or similar electrical recording instrument, connected to the contacts will indicate the flow (Fig. 27).



A moving-coil voltmeter. The coil is centred between the poles of a horseshoe magnet.

In this case the induced current flows from ring A through the loop to ring B. If these rings are connected to an outside circuit, such as an electric light circuit, the current flow will also be in a clockwise direction.

If the wire loop is given half a revolution so that the other side is adjacent to

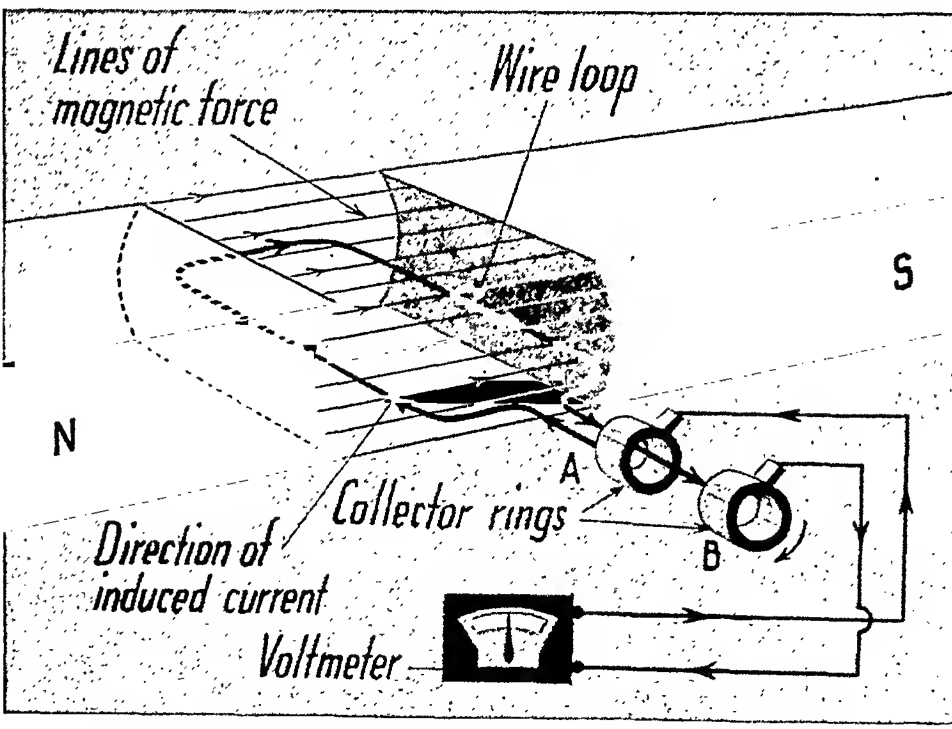
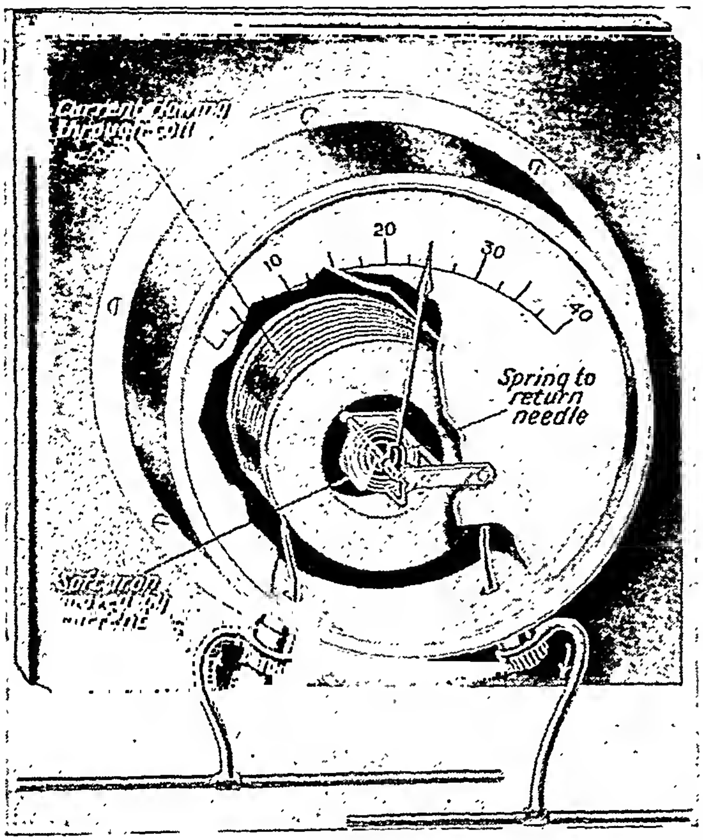


Fig. 27. Illustrating the principle of the induced alternating current dynamo.



A moving iron voltmeter. The magnet is a coil of wire in the centre of which is a soft iron armature.

the north pole of the magnet, although the current still travels clockwise round the whole loop, it is travelling towards the collector ring A from the ring B. As these rings are permanently connected to the outside circuit it will be seen that the current flows in this circuit first clockwise and then anti-clockwise. From this reason it is called alternating current—actually it is an alternate surging to and fro of the electrons in the wire.

DIRECT CURRENT DYNAMOS

We have stated that basically all dynamos produce an alternating current. Let us see how a direct current can be obtained from a machine that normally would produce only alternating current.

In the direct current dynamo no actual conversion of current is made, but by mechanical means the alternating current is so guided that the flow in the outside circuit is always in one direction. Consider again the coil of wire rotating between the two poles of a magnet (Fig. 28). Instead of each end of the wire being attached to two collector rings, only one ring is used and this is split in halves, leaving a gap between the halves. Each end of the wire loop is connected to one of these collector segments. The two collectors (C and E), or "brushes" as they are termed, are arranged to make contact one with each half ring when the wire loop is cutting the magnetic lines of force at right angles to their direction of flow.

If the wire loop is rotated as previously explained, the current is induced in the wire travelling in the direction from the half-ring A (Fig. 28) around the loop to the half-ring B, and from the half-ring B round the outside circuit in a clockwise direction back to the half-ring A. On giving the wire loop half a revolution the current flows as previously from B to A. Owing to the rotation with the loop of the half-rings, however, A is now in contact with the brush C that previously was in contact with half-ring B. As the current is now flowing from B to A, it is still passing out through brush C and returning to the coil through brush E.

In obtaining this flow or surge of electrons, the wire cuts across the magnetic lines of force at right angles to their flow when the maximum current is

induced. As the lines of force flow in practically straight lines from pole to pole of the magnet, and as the wire conductor travels in a circular path in this magnetic "field," it will be seen that the lines are only cut at right angles when the conductor is at the centre of either magnetic pole. On rotation in either direction, the angle at which the conductor cuts across the lines gradually decreases, until when the conductor is mid-way between the edges of the poles it is momentarily travelling parallel with the paths of the lines of force.

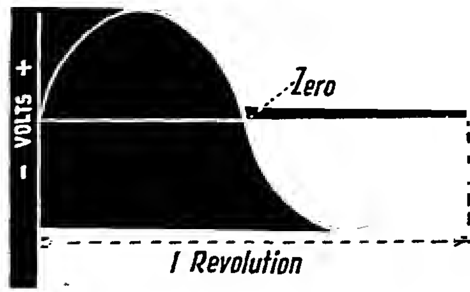


Fig. 29. Graph showing direction and intensity of an alternating current during one revolution.

ALTERNATING CURRENT

This results in a gradually decreased induced current to the point where the conductor is travelling parallel with the magnetic field. No current is induced when further rotation gradually increases the angle at which the magnetic field is cut. There is a consequent increase in the induced current, until it again reaches a maximum when the conductor is cutting the lines of force at right angles adjacent to the opposite pole, but the flow is now in the reverse direction.

If we were to draw a graph of the direction of flow and intensity of the induced current we should get a curve at illustrated in Fig. 29, in which it will be

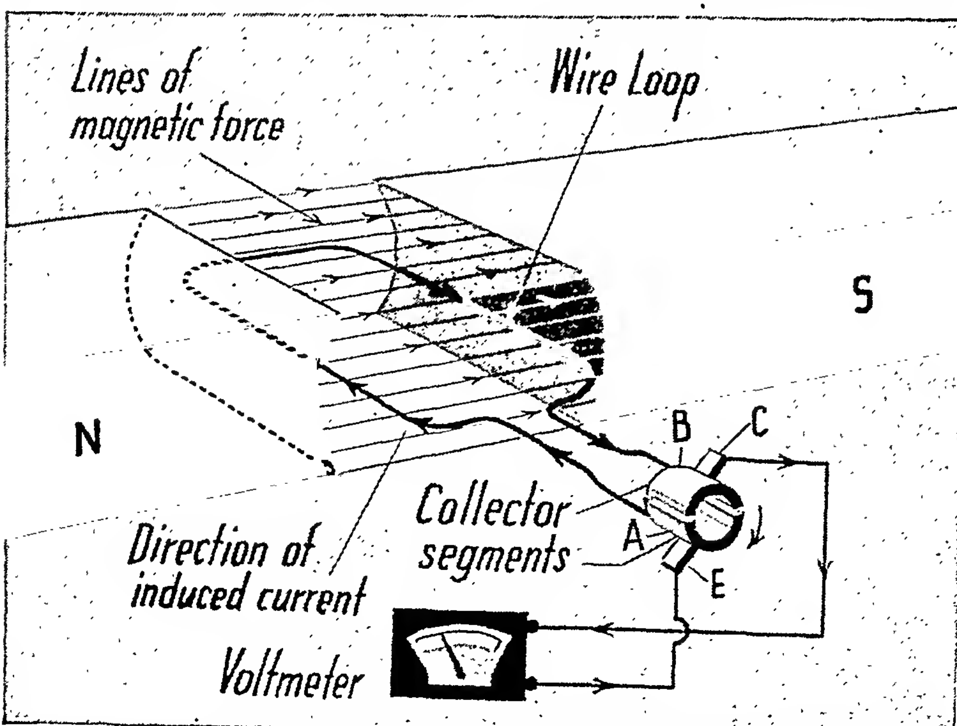


Fig. 28. How a dynamo produces direct, as opposed to alternating current (see Fig. 27).

seen that the current is in the form of a pulsation, first in one direction and then in the other. Now, in view of this we may ask how it is that we can get what is apparently a perfectly smooth flow of electricity.

If instead of one wire loop we form a number of wire loops all about the same axis of rotation, and if we connect the ends of each loop to a segment only of its appropriate collector ring, we can increase the number of pulsations per minute. Thus, if a graph is drawn of these pulsations it would take the form shown in Fig. 30, the number of pulsations being governed only by the number of coils. If these coils and segments are arranged to give a direct current, the graph would present the appearance shown in Fig. 31. This is due to the reverse, or negative, flow being transferred to the direction of original or positive flow, giving a continuous current.

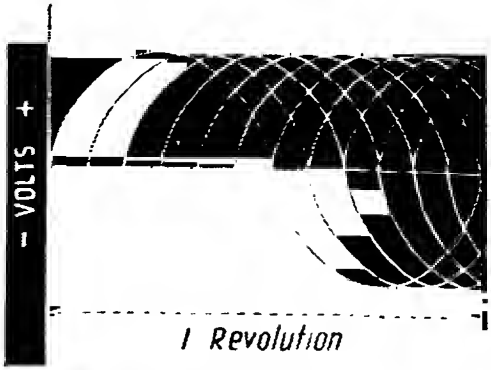
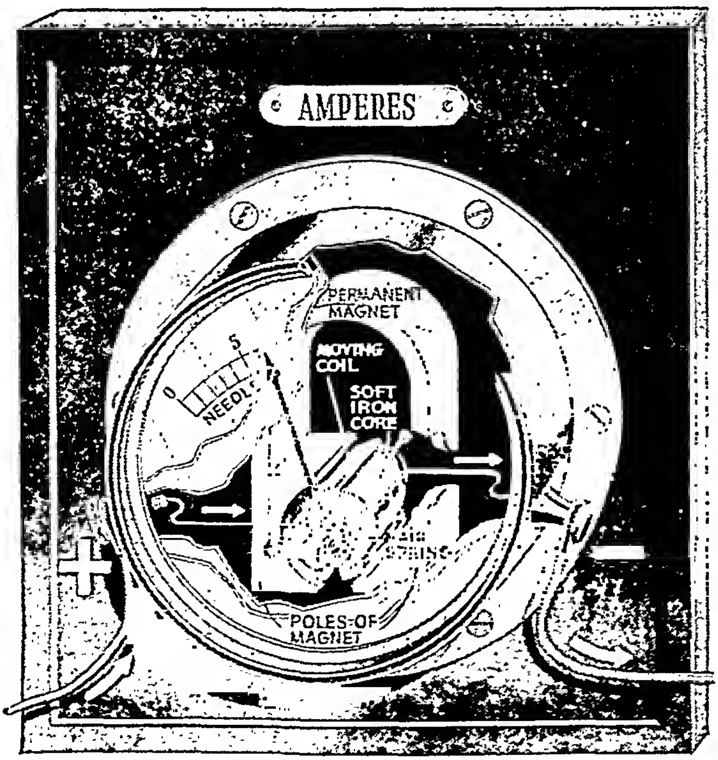


Fig. 30. A graph showing pulsations of a multi-coil alternator.

In actual practice the number of pulsations per revolution is often increased even further by arranging a number of magnetic poles around the wire coils. These are referred to collectively as the armature. In one revolution the wire loops cut through more than one magnetic field between north and south poles.

When alternating current is employed it is often referred to as being of a certain number of *cycles*. This indicates the number of times in a second that one of the magnetic fields is cut across at right angles by a wire loop. Clearly, it will depend not only on the number of loops in the armature and the number of magnet poles but also the number of revolutions per minute made by the armature.

From this we see that electric current from a dynamo is really made up of a number of rapid pulsations that may be 50 or 100, or more, per second, giving the effect of a steady flow.



A moving coil ammeter. As in the voltmeter (see page 341) the coil swings between the poles of a horseshoe magnet.

On very small dynamos permanent magnets are used as being most convenient, but on larger types the magnets are of the electro type—that is to say, they are magnets artificially induced by an electric current. An electro-magnet is formed by an electric current being passed through coils of wire wound on a soft iron core. The strength of the magnetic field depends on the strength of the electric current passed through the windings, the magnet strength increasing with the current strength.

FIELD COIL EXCITATION

It would appear from this that it is necessary to have some extra means of providing current for passing through the magnet coils before an electric current can be produced by the dynamo. This is not necessary, however, for the following reasons.

First, each end of the magnet windings, or *field coils* as they are termed, is connected to one of the brushes that pick up current from the armature. Thus, when the dynamo is generating current it is automatically supplying its own current for making the magnets. To use the usual term, it is said to be *exciting the field coils.*

When the dynamo is at rest, obviously no current is flowing through the magnet coils and therefore no electro-magnetism is induced. Yet it is necessary for a magnetic field to be cut by the armature conductors before any electricity is generated. Although this seems an impossible combination without some external initial means of exciting the field coils, such means are fortunately not necessary. As we have seen in considering magnetism, the soft iron of which the magnet poles are made has the characteristic of retaining a very small proportion of residual magnetism after the dynamo has stopped generating current.

When the dynamo is rotated, therefore, the armature first cuts through the very weak lines of magnetic force given off by the residual magnetism in the pole

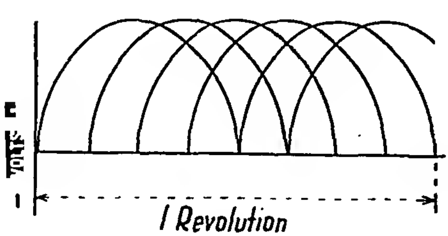


Fig. 31. A graph showing pulsations of a multi-coil direct-current dynamo.

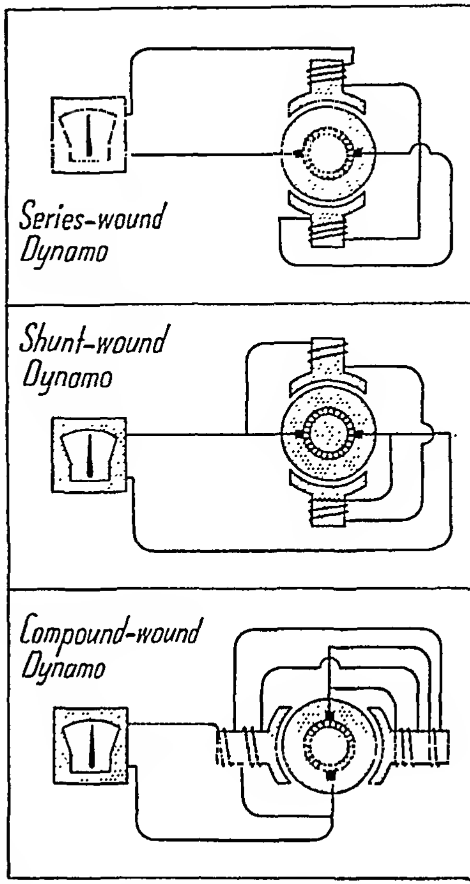


Fig. 32. Three types of generator in common use. The difference depends on the particular windings used in each case (see p. 346).

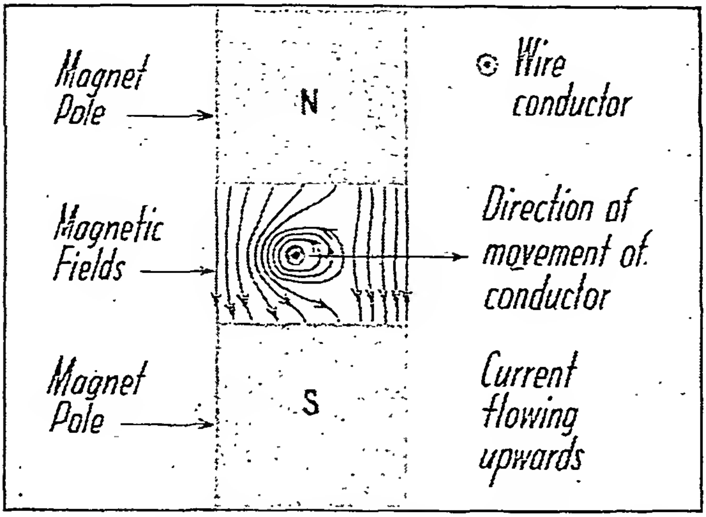


Fig. 33. How the magnetic fields in generators tend to distort each other. This is explained on this and the following page.

pieces, thus generating a very weak current in the armature windings. This weak current, passing through the magnet windings, increases the magnet strength. This, in turn, increases the current generated by the armature, the process continuing until the maximum current strength for which the dynamo was designed is reached.

Different windings are used for dynamos, and these are known as *series-wound*, *shunt-wound* and *compound wound* (Fig. 32).

The series-wound dynamo has the windings for the magnets so connected that the whole of the current generated in the armature passes through them before reaching the external circuit, as shown in the top illustration (Fig. 32). Where the windings form one continuous circuit, as in this case, the whole machine is said to be wound in series. As the load in the external circuit varies, so does the voltage, or pressure, of the dynamo current vary.

The shunt-wound dynamo, as the name implies, only passes a proportion of the armature current through the field-coils by means of a by-pass or shunt-circuit. Each end of this circuit is attached to one of the brushes through which the main current to the external circuit is passed, as shown in the middle illustration in Fig. 32. In this type of dynamo the current passed through the magnetic coils is directly proportional to the current generated by the armature. It is practically independent of any load in the external circuit.

The compound-wound dynamo is a combination of both series and shunt-winding as shown in the bottom illustration in Fig. 32. This type of dynamo is used where the generator is required to provide a constant pressure or voltage of electric current, irrespective of the load in the external circuit.

ELECTRIC MOTORS

As familiar as the electric dynamo is the electric motor that supplies most of our mechanical power requirements. In construction the electric motor is practically the same as the electric generator. It has the basic difference, however, that electric current from some external source is passed through the armature windings to produce rotation of the armature. It may seem strange that the same machine can give either electrical or mechanical power, but if we follow the natural laws governing magnetism and electricity we can realise why this is.

We have seen that an electric current passed through a coil of wire wound on a soft iron core induces magnetism in that core. This characteristic is here made use of in a slightly different way. When a current is passed through a wire, a magnetic field is induced to circulate around the wire in a direction depending

on the direction of the flow of current. If, now, the wire with a current passing through it is placed between the poles of the magnet, it will be seen that on one side of the wire the magnetic field circulating round the wire is flowing with the field of the magnets and on the other side it is opposing the magnet field. At the top of the wire the magnet field is cut across in one direction by the wire magnetic field, and at the bottom of the wire it is cut across in the opposite direction.

These two magnetic fields tend to distort each other in a manner shown in Fig. 33. As the lines of force tend to flow in their normal path they can only do so if the wire moves in the direction of the weakest lines of force. This tendency for the lines of force to flow in a normal manner results in a force on that side of the wire where the flow of the magnet field is assisted by the magnetic flow round the wire.

If now the wire is formed into a loop the same conditions exist but the force is exerted on both sides of the loop in the same direction of rotation. This is illustrated in Fig. 34 where is shown a section taken across the field magnets and the armature coil through which a current is passed.

If the current through this coil is considered to be passing downwards through the left-hand section, represented by a cross, the flow of the magnetic field at this point would be clockwise. As the current passes round the coil and travels upwards, represented by the solid section, the flow is anti-clockwise as viewed by the reader. It will be seen, therefore, that the magnetic-field distortion is above the wire where the current is passing upwards, so that both sides of the wire loop are being forced in an anti-clockwise direction.

The maximum turning effort on the armature wire occurs when the wire is

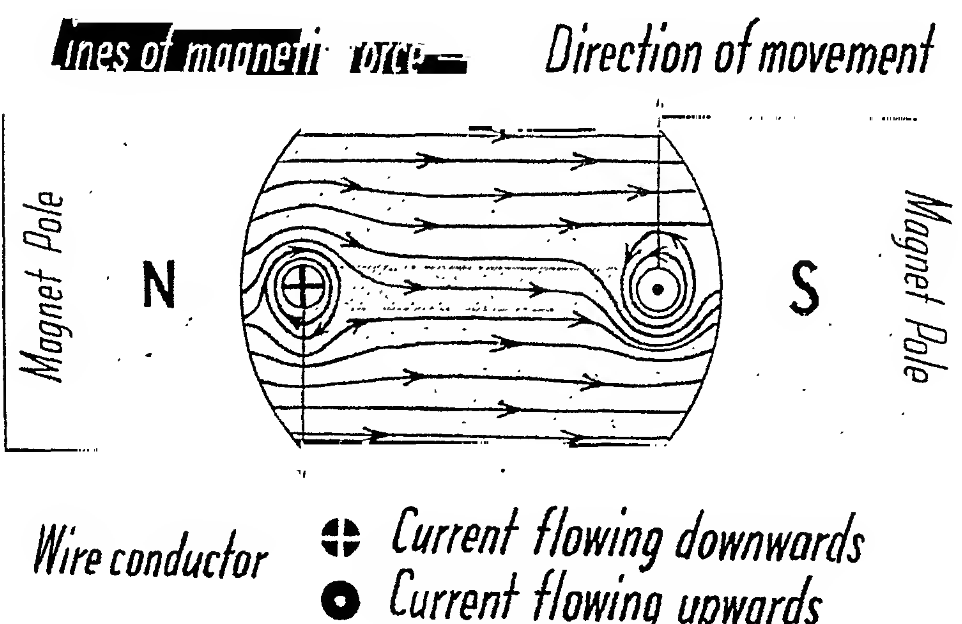


Fig. 34. Section of an armature showing clockwise and anti-clockwise flow of magnetic field.

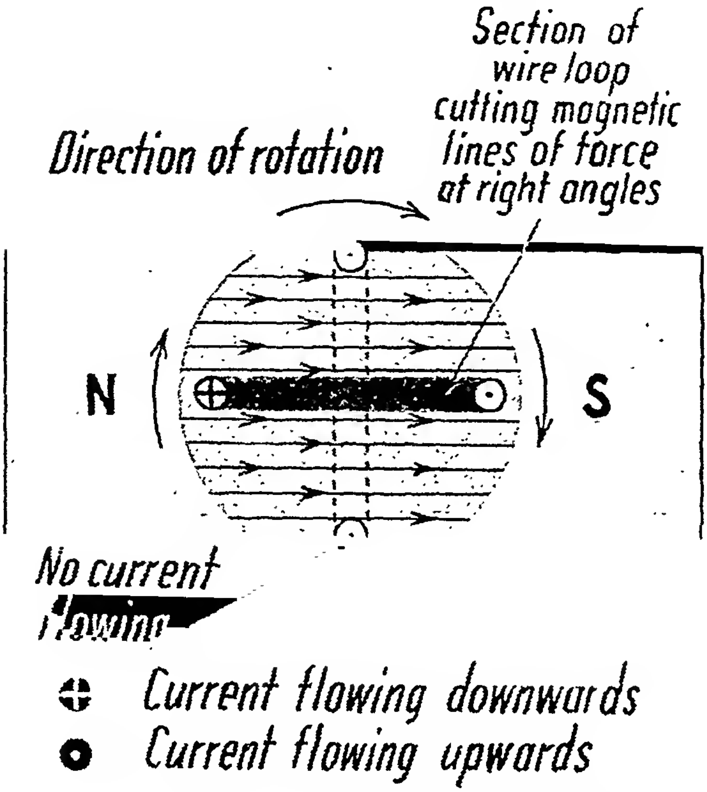


Fig. 35. Position of maximum turning force exerted on armature.

turning effort is applied to the armature, and this gradually diminishes as the opposite poles come into line.

It is obvious from this that a single coil armature would not rotate, but would only turn until it reached the neutral position. If we add a second coil to the armature at right angles to the first, however, and connect the ends to segments of the collector ring in the same manner as a dynamo, the brushes through which the current from the external source is passed can be arranged in such a position that when the first coil has reached the neutral position the segments attached to the

travelling at right angles to the lines of force. When the wire is at a point between the two poles no turning effort is exerted. In addition to this, as previously shown, magnetism is induced inside a coil of wire when a current is passed through (see Fig. 26). Irrespective of whether the wire is wound on a metal core, or whether a plain loop is formed, this magnetic field exists and has a north and south pole.

MULTICOIL ARMATURES

When the wire loop of the armature is cutting the magnetic lines of force in the maximum turning effort position, a north and south pole is generated at points midway between the magnet poles, as shown in Fig. 35. As it is a natural law for poles of a similar kind to repel each other and for poles of opposite type to attract each other, a further

ends of this coil have passed from beneath the brushes that now come into contact with the second coil through which the current is passed. This causes this coil to react in the manner already described, so continuing the cycle of operations.

In practice, a number of wire loops form an armature as in the case of a dynamo, so that the power impulses are so frequent as to give a practically smooth and continuous turning effort.

Another familiar source of supply of electricity is the accumulator, generally regarded and often referred to as a *storage battery* of electricity (Fig. 36). This is a convenient method of storing electricity in a portable form, as used for the ignition of motor-car engines and for numerous other similar purposes.

By passing an electric current through an accumulator for a certain period

certain chemical changes are caused, so that a supply of electricity is retained until current is required. By completing an external circuit, as when some electrical apparatus is connected to its terminals, the current can be drawn off from the accumulator until the supply is exhausted. Let us see how an accumulator can store electricity.

BASIS OF THE ACCUMULATOR

We have seen that an electric current is a flow of electrons from one atom to another, and that it may be caused to flow by mechanical means when following natural laws. In the accumulator, however, no mechanical means exist, the principle being one of chemical reaction between certain substances.

We have seen that the electrons of an atom are in a constantly moving state about the nucleus and that the extent and rapidity of this movement gives the substance its character. In addition to this, the number of electrons surrounding each nucleus in one substance may be greater than the number surrounding each nucleus in another substance. If by any means electrons can be transferred from one atom to another, we immediately have an unbalanced condition. As we have seen this constitutes a potential electric current when provision is made for the electrons so transferred to return to their original nucleus. If sufficient electrons are transferred this fulfils a condition that causes the two substances to change their form. It is this change of form, or chemical reaction, that is the basis of the electric accumulator.

The flow of electrons, or electric current, is greater or less, depending on the materials in contact. Such a current may be caused by various means, such as heat and cold—that is, change in temperature; by natural reaction between two substances—that is, chemical reaction; and by passing an electric current through the materials, as in the case of an accumulator.

An example of the generation of a current by the application of heat is afforded by the thermo-couple as used in an electric pyrometer. This instrument is used for recording high temperatures, such as obtain in the interior of a furnace. The element consists of two dissimilar metals attached to each other and enclosed in a fire-resisting tube for protection against heat corrosion, each metal strip being connected to a millivoltmeter through two terminals. The application of heat to the dissimilar metals, which have different degrees of conductivity, causes a more rapid and violent movement of the electrons forming the atoms, thus tending to reduce the power of the attraction excercised by their nuclei.

HOW A THERMO-COUPLE WORKS

This permits a number of electrons to be transferred from one metal to the other in proportion to the difference in their temperatures. Varying in proportion to the heat applied, this gives rise to an unbalanced state of electric potential. The balance tends to be restored through the external circuit

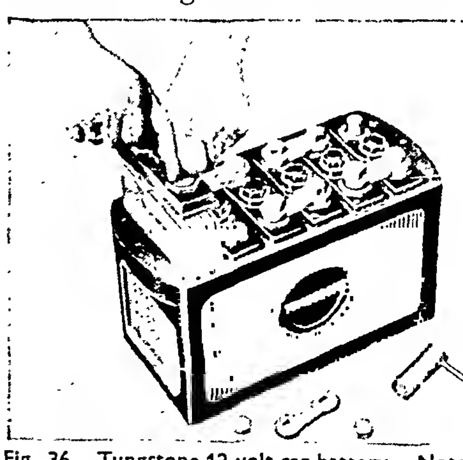


Fig. 36. Tungstone 12-volt car battery. Note the cells connected in series.

containing the millivoltmeter, by which the flow—and therefore the degree of heat applied—is recorded.

Various combinations of metals are used, according to the range of temperature it is required to measure. Those in general use are platinum and rhodium, for temperatures up to 1400 °C., platinum and iridium, for temperatures up to 1,000°C., or copper and constantan for temperatures below 500°C.

THE LEAD ACCUMULATOR

This subject is a very complex and extensive one, and it is not possible for us to give more than this very brief and general outline. It will be sufficient, however, to enable us to see what changes take place when charging and discharging an accumulator, and how the unbalanced conditions of the electrons in the various materials are affected.

The general form of accumulator is called the "lead accumulator". Its elements are constructed of metallic lead and oxides of lead, and a solution of sulphuric acid and distilled water is used as the electrolyte. This electrolyte is the medium that is capable of passing an electric current between the positive and negative plates that form the elements. This permits the chemical change necessary for the absorption of the current passed into the accumulator and for the flow of a current through an external circuit when connected to the accumulator terminals after it has been "charged". Not all liquids are capable of carrying an electric current. Pure water is not an electrolyte, but if a small percentage of sulphuric acid is added to it, it allows a current to pass. In the accumulator, sulphuric acid is used not only to form an electrolyte but also because this acid has the required effect on the lead plates during the charging and discharging process.

The plates are constructed of a lead grid or frame into which is pressed a paste having a lead base. In the case of the positive plates, this paste is composed of minium or red lead (Pb_3O_4) mixed with dilute sulphuric acid. The negative plates, which are grey in colour, are formed of a paste compound of the oxide litharge (PbO) mixed with dilute sulphuric acid, and this on combining forms lead sulphate and water.

When charging an accumulator the current is passed through it in the reverse direction to that in which it passes when it is discharging. That is to say, the positive lead from the charging board is connected to the positive plates of the accumulator, and the negative lead to the negative plates. When the charging current is switched on, the flow of electrical energy immediately attacks the water in the electrolyte and commences to separate the atoms of which it is composed so that oxygen and hydrogen gases are produced. It is these gases that have the necessary effect on the lead plates.

CHANGING SPECIFIC GRAVITY

First let us consider the necessary atoms of oxygen. These attack the lead sulphate in the paste forming the positive plates, and convert it into lead peroxide (PbO_2) and sulphuric acid. It is this acid that causes the specific gravity of the electrolyte to rise when the accumulator is charged.

The hydrogen formed by the splitting up of the water attacks the paste forming the negative plates and converts the lead sulphate ($PbSO_4$) into a soft porous lead, known as "spongy lead". This splitting up of the water is carried on until all the molecules of the plates have been changed by the combining of the gas atoms. Then further gas, liberated from the electrolyte, bubbles up and escapes to the air, a condition which is technically known as "gassing".

This chemical reaction can easily be

followed if it is expressed as an equation, thus:—

$PbSO_4 + 2\ (H_2O) + PbSO_4 +$ electrical energy $= PbO_2 + 2\ (H_2SO_4) + Pb$.

Translating this chemical formula we get:—

Lead sulphate + water + lead sulphate + electrical energy = lead peroxide + sulphuric acid + lead. To explain it even more simply, positive plates + electrolyte + negative plates + electrical energy = charged positive plates + electrolyte + charged negative plates.

One theory advanced to account for the chemical reaction that creates an electric current is that when a current from some outside source is applied to the positive and negative plates, an electric field is set up between them in the electrolyte. In addition to separating the atoms in the electrolyte, this field gives to some of them a positive or negative charge according to their nature. The atoms that possess an electric charge are called *ions*.

As we have previously seen, opposite charges of electricity have an attraction for each other. Thus the ions possessing a positive charge are attracted to the negative plate, whilst the ions possessing a negative charge are attracted to the positive plate (Fig. 37).

It will be seen that when the plates are saturated or charged an unbalanced condition exists in the accumulator. A preponderance of negative charges is formed in the atoms of the positive plate, and a preponderance of positive charges in the atoms of the negative plate. This explains the theory that the flow of current inside an accumulator when in use is from the negative plate to the positive plate, out from the positive plate, through the external circuit, and back to the negative plate.

In this unbalanced condition after the removal of the charging current, some path must be provided to allow of the

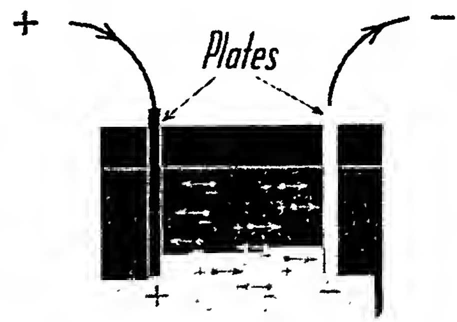


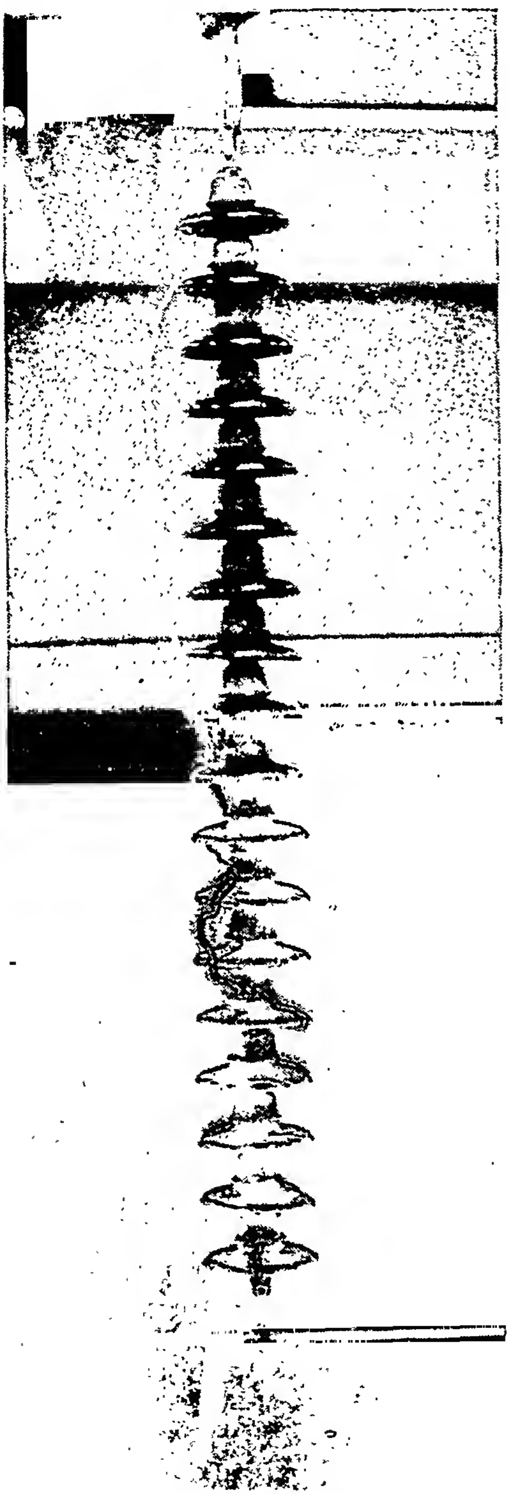
Fig. 37. Showing how positively charged ions are attracted to negative plates and vice versa.

drift of electrons that form a current—as previously described. Such a path is in the nature of a conducting material connected to the two plate terminals permitting this flow to occur. When an external circuit is so connected, a gradual drift of the electrons takes place until a balance of charged ions is obtained in the two plates. Then, as there is no unbalanced condition, the flow ceases and the accumulator is said to be discharged. The plates have reverted to their original state of composition—lead sulphate ($PbSO_4$).

RISK FROM "LIVE" RAILS

It is often asked why birds can stand without injury on highly-charged electric wires, such as overhead tram wires or overhead power cables, while when a dog or a human being comes into contact with the "live" rail on electric railways death generally results. This may seem extraordinary until it is remembered that for an electric current to flow, a complete path must be provided through some conducting substance or material. Normally, this path is provided through the mechanism of the tram or train to the metal rails on which the vehicle runs. In the case of power cables it is through the apparatus connected to them.

When a body comes into contact with a power cable and is not in contact with anything else, the body immediately becomes charged the same as the cable.



Flaws in this insulator are being shown up by a flash of over a million volts.

As it is termed, it is raised to a high potential and is therefore in an unbalanced condition electrically. As long as no path is provided to change this unbalanced condition, no flow can take place and no effects are felt by the body. If a path is provided by the fact that the body at the same time touches another conductor—which may be another wir or some conducting material connecte to the ground or even the ground itself— the path is completed and the currer flows, with disastrous effects to th intervening body.

Should a dog jump on to the liv rail on a railway, the action disconnec his body from the ground, and th prevents the current in the live rail fro flowing. He could walk on the live ra providing he breaks contact with th rail before touching the ground. he tried to step on to the rail or to ste off, however, the path would be com pleted and he would be killed.

EARTH'S NEGATIVE CHARGE

As we have mentioned, the Earth considered to carry a negative charg of electricity, due to electrons co tinually being shot off from the Su under terrific pressure. Thus by raisin the potential of any conductor—that giving a positive charge—connectio with the Earth will permit an electric balance to be obtained. It will perm the current to flow. This is illustrat by our wireless sets, for the aerial pic up a positive charge and this, aft passing through the set, is directed Earth by way of the earth terminal.

Another example is the effect of lightning that often discharges to the Earth, owing to the charge in the thunder cloud being at a different potential from that of the Earth. Any electric current always chooses the path of least resistance, and should this path be by way of property, damage is caused;

or if by way of persons, loss of life. For this reason lightning conductors of metal having good conductivity are used on high objects, so that the high potential of the thunder cloud can flow to the Earth without damage.

We have spoken of the property possessed by various materials as being either conducting or insulating. By this we mean that a material either will readily permit the passage of an electric current, or it will offer such a great resistance to passage that no current flows. On the other hand, it has been seen that the electrons that form an electric current—under certain conditions—are a part of all matter. In view of this we may wonder why some materials will permit a current to flow more readily than others. Particularly in the case when there is what is called an insulator "breakdown", whereby it is made manifest that even those materials possessing the property of insulation can sometimes allow the flow of current.

No material is a perfect insulator, and providing that a sufficiently powerful current can be applied, all materials will permit the passage of a certain amount of electricity.

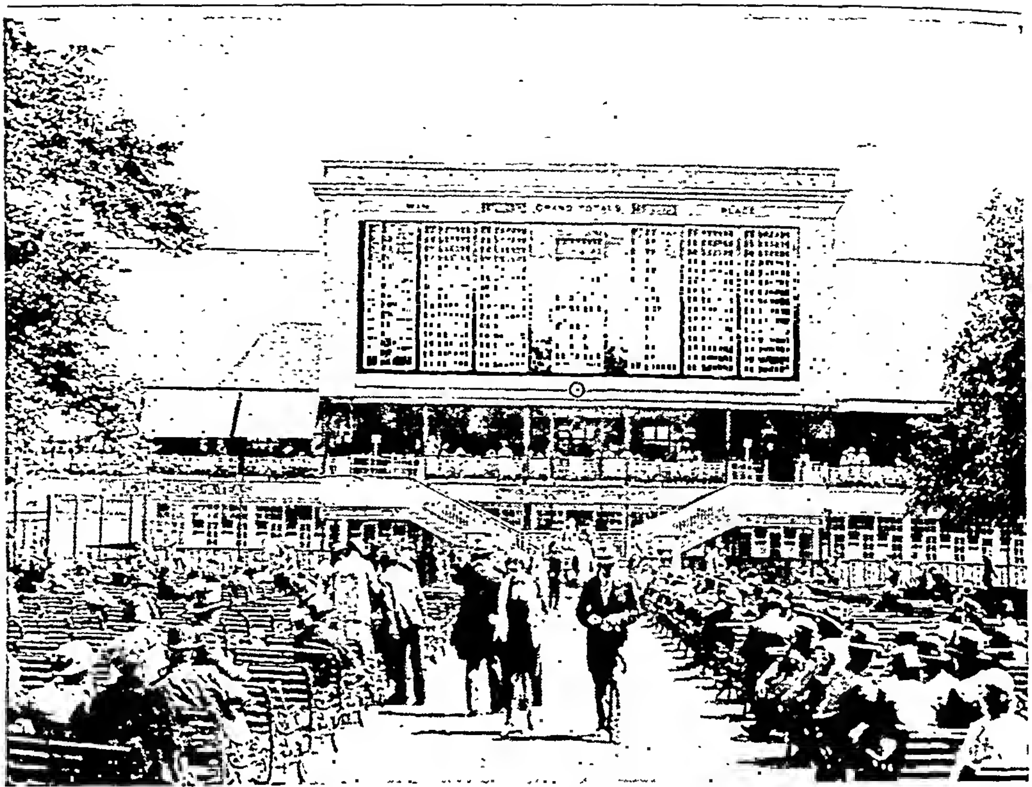
It has been shown that all matter is composed of an assemblage of positively-charged nuclei, about which revolve electrons that are negatively-charged. We have also seen that it is the rate of such revolution and state of this vibration that determine the characteristics of the body, the attraction existing between the differently charged particles retaining the body as a homogeneous whole. Further we have pointed out that, depending on the particular material, the number of electrons in orbit about a nucleus varies to a greater or lesser extent; and that, although electrons can be transferred from one nucleus to another, no current will flow, providing that the balance is maintained throughout.

In any one material the number of electrons about each nucleus will vary, and it will be appreciated that owing to the infinitesimal distance between each nucleus the path or orbit of each electron system will overlap. Under these conditions a number of "free" electrons, which have less attraction to the nucleus than others, come into the field of attraction of an adjacent nucleus to which they are transferred by its attraction. This state continues throughout the whole body, so that there is a constant movement of electrons from one nucleus to another. This preserves an electrical or potential balance, although the direction of movement is not constant and varies with each moving electron. According to the nature of the material, this transference of electrons takes place with greater or lesser ease. It is this degree of ease that may be considered basically to determine whether the material is a conductor or an insulator.

MOTION OF FREE ELECTRONS

It has been seen that two charges of different characteristics—that is, positive and negative—tend to attract each other. Therefore, if a positive potential is applied to the material there would be a tendency to attract the negatively charged electrons. When an electrical circuit is completed through a material this negative-potential, or current, is applied. This tends to attract those electrons that are said to be "free" and are in a constantly moving state of transference. Thus, instead of their direction apparently being indiscriminate they are attracted by the negative potential in one direction only—that is towards the positive side of the external current-producing apparatus.

We now see that a condition previously described, is obtained of a controlled directional flow of electrons.



Courtesy of Automatic Telephone Manufacturing Co., Ltd.

The all-electric totalisator installed at Ascot demonstrates yet another example of the way in which electricity is being applied to every form of human activity. The totalisator is worked on the switchboard principle and records the amount invested on each horse bet by bet.

As previously stated, these form an electric current and the magnitude of the flow determines the degree of conductivity of the material. If a considerable flow is obtained, the material is said to be a good conductor. On the other hand, if the flow is very small or apparently nil, the material is said to be a bad conductor, or an insulator.

ELECTRICITY HARNESSED

It is one thing to discover the cause of natural phenomena in the laboratory but an entirely different thing to apply this knowledge in controlling natural forces so that they may be turned to practical assistance in everyday life. All forces of Nature are tremendous in their magnitude and if uncontrolled—or worse still, if allowed to escape from the control Man endeavours to impose on them—they can cause enormous damage. This is especially true of electricity. The natural electricity that is visually manifest in the lightning flash is a potential source of great danger. To counteract this danger, it becomes necessary to employ some means, if not of actual control, at any rate to guide this force so that no harm results from its discharge. The lightning conductor does this by providing an easy path to the Earth, but where no such easy path is provided anything in the path of this electrical discharge is destroyed. Everyone knows of the danger of being "struck by lightning", where buildings, trees, animals, and human lives are lost through being in the uncontrolled path of this natural force.

No less dangerous is the electricity produced by Man. Here the major

problem is not the actual production, but the means of controlling the force so that it can be used to practical purpose. The mere production of electricity is comparatively easy and not costly, and far greater expense is incurred in apparatus for its control and distribution.

CONDUCTORS AND INSULATORS

Nature always provides some means of preserving a balance of forces. With electricity it may be said that such balance, or protection, is afforded by the various materials that have a natural property of resisting or preventing the passage of the current. These materials play a large part in assisting Man to construct apparatus to enable him to control the force he generates.

In the most common form of electric lighting use is made of the property of resistance in a material. This form is the incandescent, or glow lamp, that in its earlier days comprised what is known as a carbon filament. It was made from a paste of cotton wool dissolved in zinc chloride. The paste was forced through small holes into alcohol, so causing the paste "wires" to harden to allow them to be bent to the shapes required. These shapes were then packed round with carbon powder, and heated to about 550°C. and so were converted to the carbon filament ready for use.

Such a filament offers a resistance to the passage of an electric current, and in overcoming such resistance it is made to give a portion of its energy as heat. If the current is small, the amount of heat is so small that it is lost in conduction and radiation. On the other hand, if the current is large an increasing amount of heat is given off and it will eventually be sufficient to cause the filament to become red, or even white hot, thereby giving the required light.

Exactly the same process occurs in modern lamps. Instead of a carbon filament they have one of metal—usually of tungsten wire—and in addition the air removed from the bulb is replaced by an inert gas. The purpose of removing the air is to prevent oxidisation of the filament when heated, so causing early failure of the lamps. A vacuum alone does not give a good light as we know it to-day, therefore a gas is introduced to permit the filament to be heated to a greater extent and give a better light than would otherwise be possible.

Current in towns is conveniently distributed from powerful generators through switchboards and resistances direct to the lighting points. Where no such facilities exist, other methods have to be used to harness electricity in such a manner that its energy is available when required, irrespective of a continually working power station. In these cases, the dynamo generating the current is driven by petrol, oil, or gas engines, but instead of delivering the current direct to the lighting points, it supplies it to a battery of large accumulators. The lighting supply is drawn direct from the accumulators so that current is available even when the dynamo is not in operation. The dynamo set requires to be run only for comparatively short periods at a time to charge the accumulators sufficiently to replace the current used during its idle times. Apparatus of this type is often used in country houses and is also installed in many large city buildings as a precaution or reserve against a breakdown in the mains supply.

THE WORLD'S BRIGHTEST LIGHT

Another form of lighting is the carbon arc lamp. Here use is made of the fact that an intense spark occurs when an electric circuit is broken, due to the current endeavouring to continue to flow. A spark thus formed reaches

very high temperatures and at its hottest point may be from 3,500° to 4,000°C., giving the intense glow of light that is characteristic of the arc lamp.

The two electrodes between which this spark is formed must obviously be of some material that will not melt under this extremely high temperature. For this purpose carbon rods are used. The positive electrode is usually larger than the negative electrode as it is subjected to a greater degree of heat. Although carbon will not melt under these conditions, some burning takes place and a crater is formed on the positive electrode (Fig. 38). Here is generated the greatest heat, giving the major source of the light.

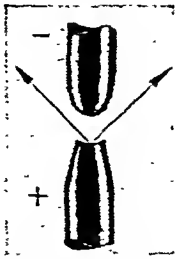


Fig. 38. Showing the crater that is formed on a positive carbon electrode.

Arc-lighting is extremely valuable where a point of light is required, such as in large ciné projectors and searchlights. With the aid of mirror reflectors an intense narrow beam can be obtained, such as would not be possible with a light given by a filament covering a comparatively larger area than the other.

LIGHT FROM ELECTRON STREAMS

A third method of providing light is the effect of passing an electric current through a gas. This does not mean that the gas burns, for it merely glows through ionisation. It has been found that when an electric current is passed to an electrode—the cathode—set in a gas, a glow takes place. In addition, the rays—called "cathode rays"—emitted from the electrode have a definite heating effect. These rays are considered to consist of a stream of electrons—negative particles of electricity—that are divorced from their parent atoms. The remaining portion is positively-charged, and the portions so formed are the ions, to which we have already referred. An unbalanced condition is now obtained and the gas is said to be ionised, as we have mentioned in an earlier chapter.

This ionising process excites radiation from the gases in which the cathodes are placed, so causing the intense glow and giving the light that we see in the advertising signs in all towns and cities. Various gases—such as mercury vapour, sodium, neon, argon, etc.—are used to give different colours or effects.

The next most familiar means of harnessing electricity is where it is required for power transmission. The modern method is commonly known as the "Grid" system, the pylons of which are now a familiar feature carrying the cables overhead across the country. Here, use has been made of certain natural laws to overcome one of the greatest obstacles to transmitting a current over long distances.

We have seen that all materials, even the best of conductors, offer some resistance to the flow of a current. Therefore, a certain percentage of current is always expended in overcoming such resistances, before the remainder is available to perform work by means of various electrical devices.

It will be realised that when the distance over which the current is to be transmitted is very great an enormous quantity of current would be required if users at the farthest end of the line were to obtain sufficient for their needs. To carry this an enormous quantity of current would necessitate such extremely large and heavy conductors as to make such schemes entirely impracticable. Therefore, the condition of self induction, in apparatus known as transformers, is utilised in the following manner.

When a coil of wire is placed close to,

but not touching, another coil of wire, and the ends of the first coil are connected to a battery, it will be found that on closing the circuit there will be a sudden surge of current in the second coil. If now the switch in the circuit of the first coil is thrown open so as to break the circuit, a surge of current will again occur in the isolated second coil. If a sensitive current-recording meter is connected to the ends of the second coil it will indicate that the direction of the current is the reverse of the current surge when the switch in the first coil circuit was closed. This phenomenon is termed mutual induction, the current running in the second coil being known as an induced current.

TRANSFORMERS AND A.C.

It is not necessary to make and break the circuit in the first coil, however, to induce a current in the second coil. The same effect is produced if the primary current is reversed in its direction of flow, a current being induced in the secondary coil each time a reversal is made.

By varying the ratio of the number of turns of wire and the thickness of wire in each coil, it is possible to obtain from the secondary coil a current different from that supplied to the primary coil. If the primary coil consists of a large number of turns of fine wire, and the secondary coil of a comparatively small number of turns of a thicker wire, the induced current in the secondary coil will be smaller than that supplied to the primary coil, and vice versa. In practice the coils are usually wound on a soft iron core to increase the magnetic field that is the cause of the induced current.

The transformer thus provides the means of overcoming a major difficulty in the transmission of electrical power. A small current is first generated at extremely high pressure, or voltage—possibly as high as 60,000 volts. Owing

Courtesy of the General Electric Co.

Electricity used for welding purposes. From the arc formed between a positive and a negative electrode sufficient heat can be obtained to fuse heavy metals together. The welder must use a shield to protect his face, the eyepiece being made of mica.

to this high pressure, only relatively small conductors are necessary to carry it over long distances. This high tension current is then led to a sub-station in the district it is intended to serve, and here it is fed into huge transformers. They convert it into a low-voltage current in sufficient quantity to serve a predetermined area, over which it can be carried by suitable conductors.

HEATING BY ELECTRICITY

Harnessed for further uses, electricity gives us heat in degrees of sufficiently wide range to serve both domestic and industrial purposes. Everyone is familiar with the electric "fire", or radiator, in which the characteristics of the energy of electricity in overcoming a resistance to its flow are caused to manifest themselves as heat.

We have seen that electricity is a movement of certain particles of a body or material, and it has been stated that the characteristics of that material and its temperatures depend on the rate of such movement. When a current is caused to flow, therefore, additional or increased movement is imparted to these particles so causing the sensation we know as heat. Should the body through which the current flows be small in proportion to the amount of current, and should the material be one having the characteristic of high resistance, the accelerated movement of the particles will be sufficiently great to cause the body to glow and radiate an appreciable amount of heat. Through this medium, the domestic electric fire serves its purpose, the glowing elements being a wire having a high resistance to permit a heat glow. Radiation is assisted by reflectors of metal, or of some form of fireclay that projects the heat-rays into the room.

The welding of metals is another use to which electricity is harnessed. Here, the heat of the arc between two electrodes is used to effect the necessary fusion. In this case, one electrode is formed by the metal that is to be welded and the other by a quantity of the same metal as that to be welded. This latter electrode, which is the one handled by the operator, is made in the form of thin rods of various thicknesses. This enables a light current and therefore a small arc to be used for fine work or in welding sheet metal where too intense an arc might cause burning of the job. Thicker rods are used where heavy jobs are undertaken, or where the mass of metal conducts heat away from the affected part very rapidly.

As with all forms of soldering, brazing, or welding, some form of flux must be used to float to the surface slag and impurities due to the oxidising effect of the arc. For convenience of working, this flux, in the form of a compound, is formed as a coating on the outside of the welding rod. Thus, as the rod fuses, a predetermined quantity of flux is also supplied directly to the weld. In operation, the welder holds the rod electrode in a special pair of tongs and strikes an arc at the spot to be welded. The intense heat of this arc immediately melts the end of the rod electrode and also a portion of the metal to be welded, so that complete fusion and mixing of the two metals is effected and the weld actually becomes a homogeneous part of the job.

Under test it has been found that a good weld actually is stronger than the original metal. Weld fractures are seldom experienced.

Welding is not the limit to which the heat of an electric arc can be used, however, for on a larger scale it is used as a furnace in which steel can be made. The electric furnace is extremely useful for producing steels of very high quality. An important factor is that the intense

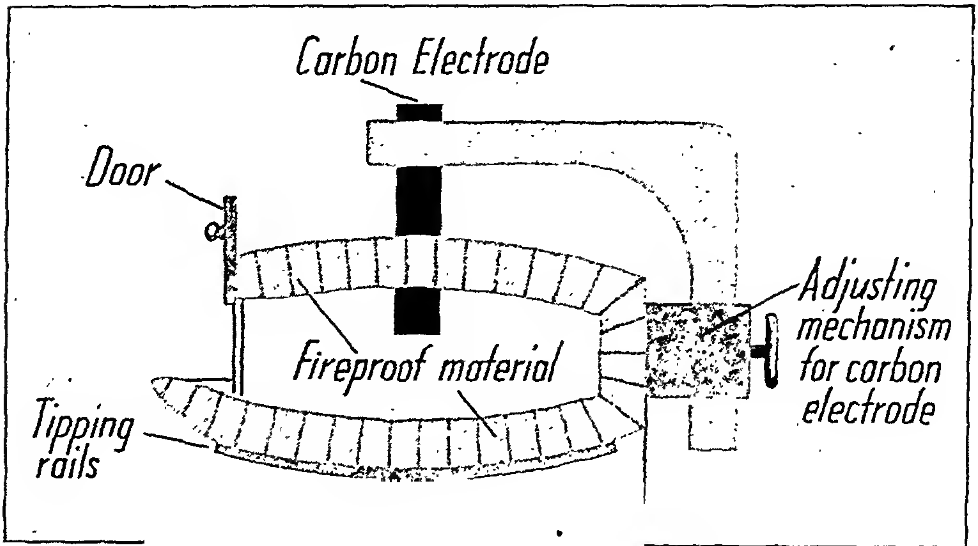


Fig. 39. Showing how electricity can heat a furnace by the arc method (see text).

heat enables such impurities as sulphur and phosphorous almost to be eliminated.

Exactly the same methods are used in the electric furnace as in welding—that is, the charge fed into the furnace forms one electrode, a heavy adjustable carbon rod forming the other (Fig. 39). According to the size of the furnace, one or more carbon electrodes are used (Fig. 40) each being adjustable by external gearing to give the correct height in relation to the charge. Current from electric generators is supplied to the charge. It passes through this to the carbon electrodes and through them out of the furnace back to the generators to complete the circuit.

In the electric furnace use is made of the characteristic of the resistance of the

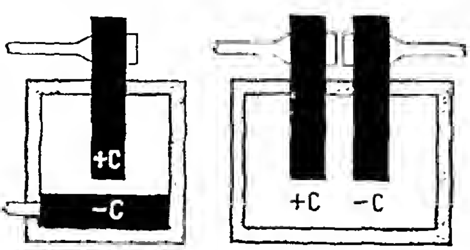


Fig. 40. Alternative arrangements of carbons as used in an electric furnace.

charge, by first lowering the carbon electrodes until they are in contact with it. The current is then switched on and the resistance of the charge causes it to heat up to a point at which it is partially melted. Then the carbon electrodes are raised and carefully adjusted until an arc is formed between them and the surface of the charge. The heat formed by such an arc is sufficient to make the charge fluid enough for working. It allows of the addition of other materials necessary for steel manufacture, and the formation of a fluid slag and impurities that are drawn off.

HOW THE MICROPHONE WORKS

The foregoing examples show the harnessing of electricity in comparatively large quantities, but this does not mean that only such large quantities can be harnessed to perform useful work. Even small quantities of electricity are harnessed to serve some useful purpose by the ingenuity of engineers in inventing and constructing suitable apparatus.

We take as an example of this, the transmitting microphone of the telephone and its receiver (Fig. 41). In the

former, use is made of the characteristic of a carbon contact being of high resistance but extremely sensitive to mechanical disturbance. This component has as its basic features a metal diaphragm and a carbon contact block, between which is a quantity of carbon granules to increase the points of contact between the block and diaphragm. Only a small current is now necessary for the microphone to operate in the following manner.

WHAT THE DIAPHRAGM DOES

When a sound is made into the mouthpiece of the microphone transmitter, the sound waves so formed strike on the face of the diaphragm, and this vibrates in sympathy with them. This movement, which is imperceptible, is transmitted to the carbon granules and block. Owing to this vibrating disturbance, these alter the resistance to the passage of the current in the circuit through their points of contact. This therefore, alters in proportion to the amount of current flowing in the circuit. It only remains to record these fluctuations in current strength in a suitable manner to reproduce the sound made in the transmitter.

For this purpose the effects of an electro-magnet are used. The receiver is somewhat similar to the transmitter, but the soft iron diaphragm is placed very close to the two poles of a permanent magnet on which are wound a great number of turns of very fine wire. When the instrument is not being used, the lines of magnetic force flow from the north pole of the permanent magnet, through the soft iron diaphragm—although this is not touching the poles—and back to the south pole of the magnet. Thus, a constant pull, or attraction, of predetermined strength, is maintained throughout in the diaphragm.

FROM SOUND BACK TO SOUND

As the ends of the magnet coils are connected in circuit with the transmitter, it will be seen that any variation in the current strength produced at the trans-

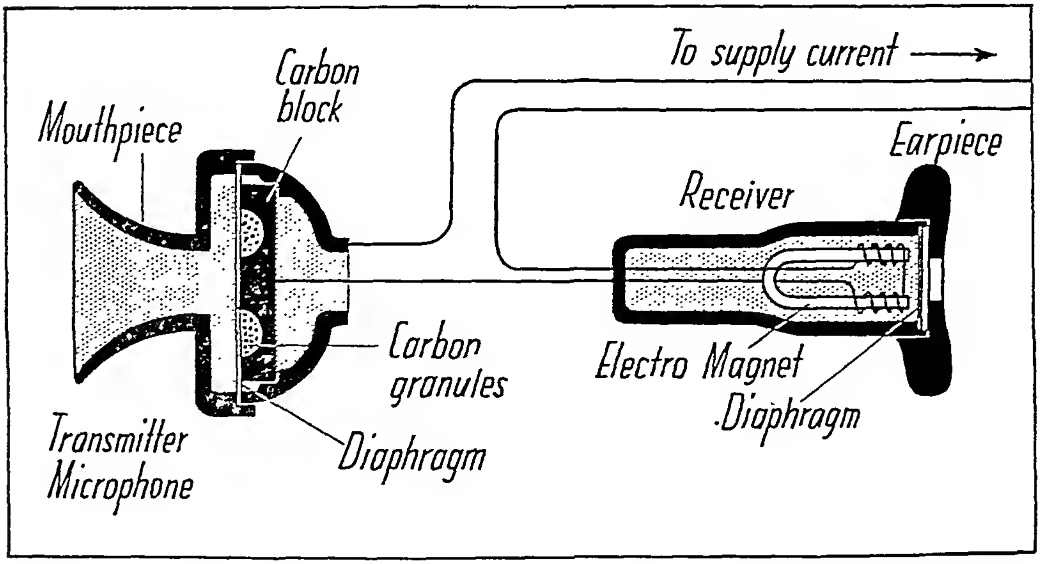
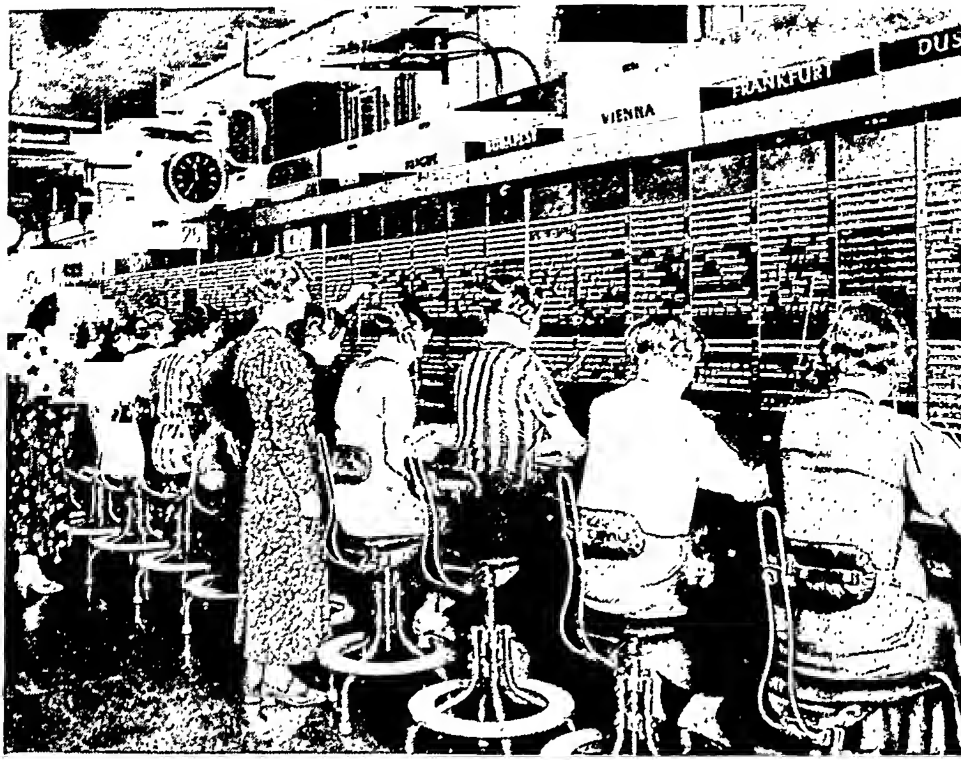


Fig. 41. Sound waves striking the diaphragm of the microphone alternately compress and release the carbon granules. Their resistance to the current flowing in the circuit is thus altered and these fluctuations in current produce variations in the pull of the magnet in the receiver. Its diaphragm is in turn caused to vibrate and thus produce sound waves.



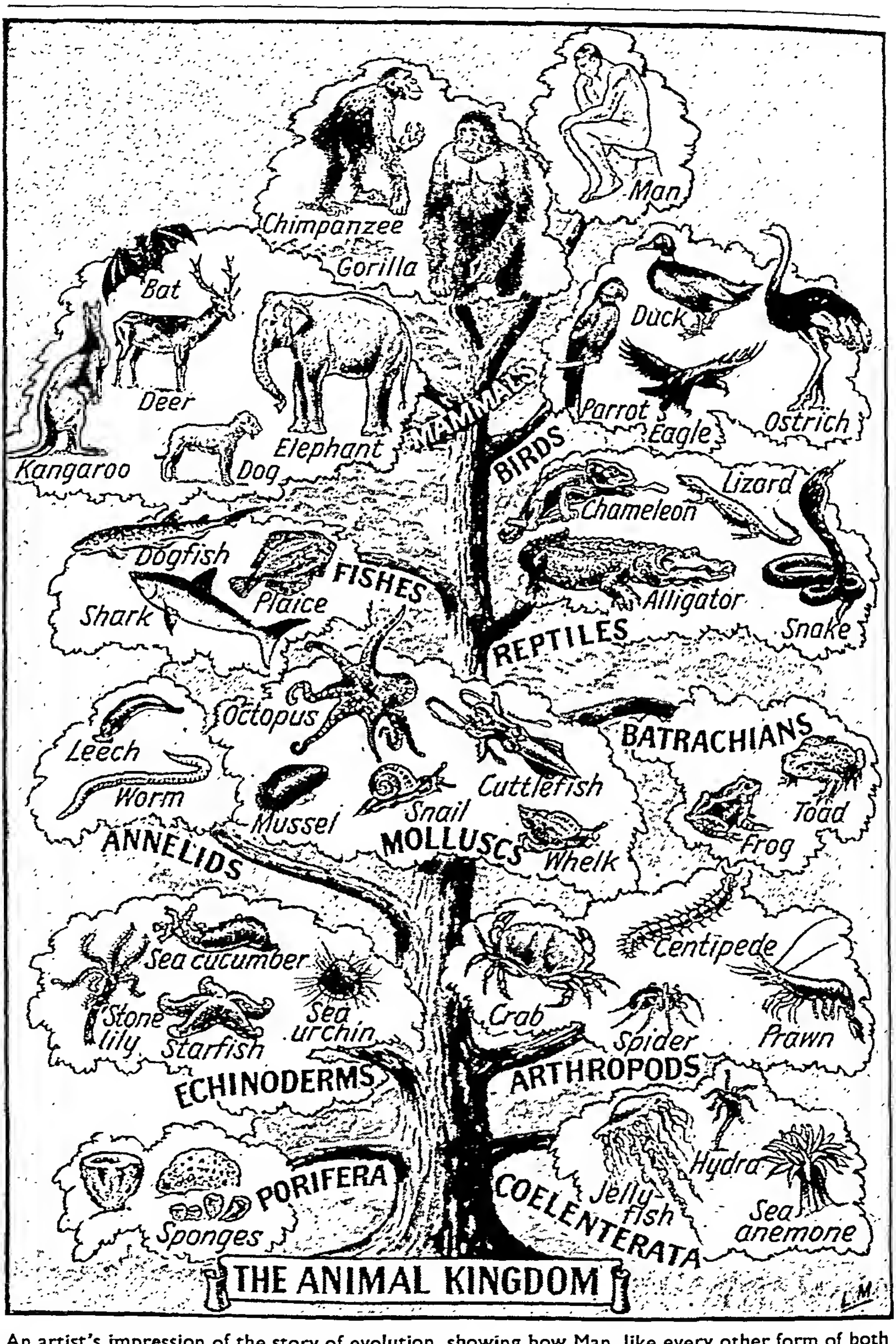
Courtesy of the Postmaster General.

TELEPHONE CALLS FOR ALL THE WORLD

Owing to electricity, people all over the world can speak to each other across many thousands of miles. Here is seen part of the International Telephone Exchange in Faraday House, London, with the staff at work. Calls to the continent go by land line and cable, transatlantic calls by land line and radio. Outgoing radio-telephone calls are transmitted from Rugby and the answer received at Cupar. The words of the speaker are "scrambled" so that no one can possibly "listen-in".

mitter will be effected throughout the circuit and the magnet coils in the same proportion. Such variation of current in the magnet coils increases or decreases the strength of the permanent magnet, and with it its attraction of the diaphragm, which under this varying attraction vibrates in exactly the same way as the transmitting diaphragm. Such vibration in the receiving diaphragm is immediately imparted to the air, in which waves are set up forming the sound it is intended to receive. This is merely the basic principle of one piece of modern apparatus for harnessing small quantities of electricity. Many refinements and additions are made to enable greater convenience and use to be obtained.

The effects of harnessed electricity are seen on every hand. Our transport in the form of electric trams and trains, our lifts and cranes, conveyors and escalators, are driven by electric motors. Innumerable domestic appliances, and surgical and medical apparatus, result from the continual effort of Man to harness to his needs one of Nature's greatest and most potent forces.



An artist's impression of the story of evolution, showing how Man, like every other form of both plant and animal life, is descended from common ancestors.

SECTION IV

THE MARVEL OF LIVING THINGS

CHAPTER 16.—THE ANIMAL WORLD

WHETHER life originated on this planet, or whether it arose from protoplasmic material (the substance of which animals are made) that somehow arrived here from another planet, is uncertain. What is certain, however, is that life began in a very simple form. Only after long ages of experiment; of adaptation to the slowly changing conditions of a cooling and drying Earth; of steady improvements on the upward scale; did Nature's basic plan succeed. To-day there are over 700,000 known species or variations of form and habit in the animal world alone. Each is devised as best to comply with the many variations of conditions under which life must struggle to survive. It is because these conditions are not constant that life must continually be adapting itself to their changes, and for this reason, change, or evolution, is still going on to-day. So very slowly do things evolve that we do not always appreciate the importance of the changes that are taking place under our eyes, but we shall see later how they are happening.

When we speak of "life" we mean that state of an animal or plant in which various organs are capable of performing their functions—that state in which a series of definite and successive changes take place in both structure and composition without interfering with the identity of the individual.

Living material, or protoplasm, exists in cellular form. Some of the simplest animals consist of but a single cell with a protective wall, whilst in the higher animals these cells are specialised according to their various functions. All living cells, whether single or specialised, have the marvellous power of converting non-living, or "dead", matter into living protoplasm. This may be likened to a combustion or burning process for which air, or more correctly oxygen, is required, so that the living animal must breathe or respire.

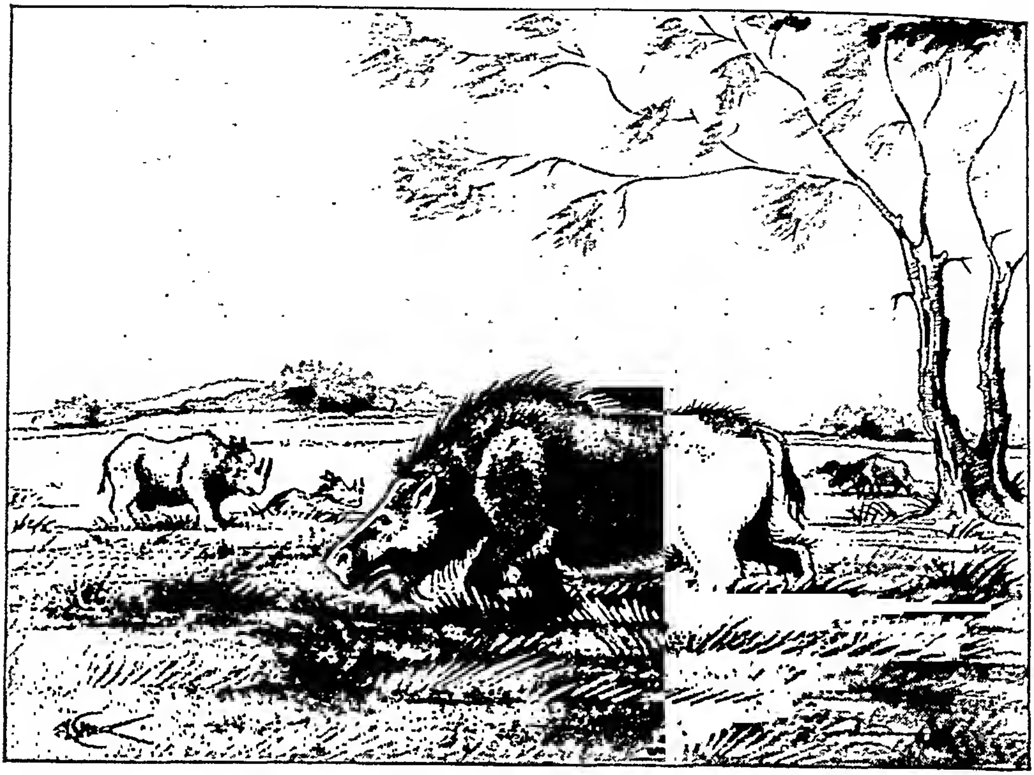
Arising from this process there is the animal heat, produced by life, that is so noticeably lacking in dead or inorganic things. There is also the need for regular supplies of fuel to the "furnace" in the cell, hence an animal must feed. And there is the production of waste material, hence the need for excretion.

ANIMALS AND PLANTS

As animal life is much more complex and highly developed than plant life, animals require far more food than do plants. Generally, they are unable to find sufficient supplies in one place: hence arises the need for locomotion or movement. As these animal forms may be destroyed through fire or starvation, or by getting into conditions where there is a lack of oxygen, some precaution has to be taken to ensure the future of the life, and so we get reproduction.

It seems that throughout the whole of her schemes Nature puts the future of the race or species before that of the individual, and that the sole purpose of each living form's existence is to reach maturity, to reproduce its own kind, and so prolong the race. Life that cannot reproduce is of no further use to Nature.

The small tortoise-shell butterflies that flit over the stubble fields after



The two horned rhinoceros and the giant pig. Some twenty million years ago huge mammals like this roamed the Earth, but they have long since become extinct.

autumn harvest are females full of precious eggs and therefore valuable to Nature. They hibernate through the cold winter frosts in the garden tool-shed or in some hollow tree, emerging again in the warmth of spring to lay their eggs, having done which they soon die. The same remarks apply to the gnats and queen-wasps that hibernate through the winter to lay their eggs in spring and so preserve the continuity of the race, for the old male gnats and tortoise-shell butterflies are killed off by the autumn frosts and do not hibernate.

On the other hand, the worker bees and the soldier ants do not die in the autumn because they are valued by Nature because of their work for the community of the hive or the ant-hill. Here the duties are shared out between the inhabitants, so allowing reproduction to be specialised in one or two insects. These are able to reproduce at a phenomenal rate for they have no other duty to perform.

The fact that the autumn butterflies and gnats have to hibernate to escape the winter frosts, and that the male gnats and butterflies that do not do so are killed off, suggests that life is not possible under certain temperatures. Actually, life is most abundant and active in the Tropics and Temperate regions. On the other hand, the Polar regions have little life except during their brief summer.

Because life here is only possible under the average temperature range, we know that most of the planets probably are either too hot or too cold to support life as we know it. According to some, planets that are now cold were warmer in the past. They may have supported life that became extinct when conditions

became too cold. Similarly, the hotter planets may be able to support life in time to come when they have cooled sufficiently. It may be, then, that life has moved from planet to planet as each cooled in turn; that it came to the Earth from Mars, and when our cooling planet becomes too cold, Venus will have cooled sufficiently to support it.

FIRST APPEARANCE OF LIFE

Whatever may have been the case, we believe millions of years were required for the Earth to cool sufficiently to allow the formation of a solid surface, and for the steam of the surrounding vapours to condense to form the water for its oceans and rivers. When the temperature was suitable, life appeared in its simplest form—probably in the sea, for at that time water was abundant on the Earth. Then began the great struggle for existence that has been Nature's battle and every creature's battle down to Man.

This struggle—the modification, advancement, and adaptation—from the earliest forms of life to Man, has not been the ladder of progress that some people consider evolution to be. We can picture it better by thinking rather of a tree with many branches, some of which have not yet ceased growing, whilst others are now flourishing as specialised groups of animals such as the mammals, the birds, the fishes and the reptiles. Other branches appear to have ended blindly and abruptly when Nature chanced to produce a form of life that seemed to be almost a failure although adapted to certain conditions. For example, it seemed to be impossible to find a place for the giant reptiles in the conditions that followed their creation—conditions not necessarily brought about by any sudden change, but the results of constant and persistent changes going on in the world.

Our tree of evolution would start then with such simple forms of life as the Protozoa, or single-celled animals. It would then grow through such forms as the *Ceolenterates*, or animals with a body-cavity, such as the worms. Having branched off into such simple improvements as the sponge-colonies and the starfish, it would pass through the Arthropods, or jointed-bodied animals —like the Crustaceans (crabs and lobsters)—the Molluscs or "shellfish" (snails and oysters, for example), to the Spiders and the Scorpions, and then to insects.

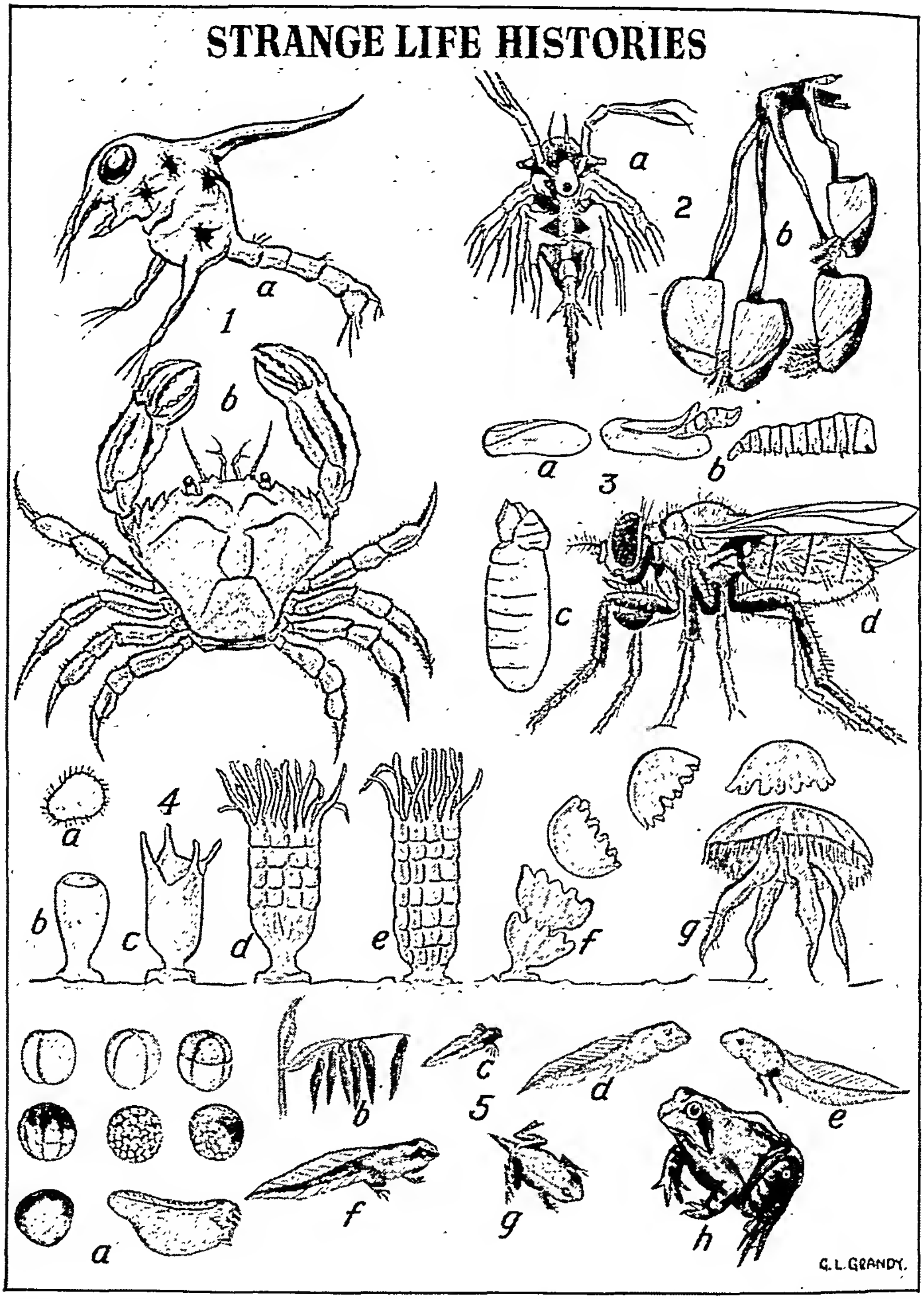
Progressing upwards, it would branch off to the Fishes. They showed a big improvement on the other creatures in having a backbone. Their hard bones could be used as attachments for the outside muscles, so allowing them to continue to grow unhampered by a hard shell, as was necessary with such forms as crabs and lobsters, beetles, and the higher Invertebrates—or backboneless animals—all of which required a protective container for their soft bodies.

AMPHIBIAN LIFE

Further progress was indicated when some of these sea creatures were able to spend part of their time in shallow water, or even on the drying land that was appearing. This step resulted in the coming of the Batrachians, or amphibians, the ancestors of our frogs and newts. In turn, they were followed by the great branch of Reptiles, that were capable of living permanently on dry land. They also were backboned animals and were thus suited for greater experiment than the invertebrate insects that also dwelt on land.

These improved forms of life, the backboned animals, did not inhabit the air, but from the reptiles, there branched off a flying variation—the Birds.

Meanwhile evolution had produced in



1, Crab (*a*) larva, (*b*) adult. 2, Barnacle (*a*) free swimming larva, (*b*) sedentary adult. 3, House fly (*a*) egg, (*b*) grub, (*c*) pupa, (*d*) adult. 4, Jelly fish (*a*) free swimming egg, (*b* to *f*) sedentary, (*g*) free swimming adult. 5, Frog (*a*) egg grows into tadpole, (*b*) with suctorial mouths, (*c*) with external and (*d*) with internal gills, (*e*) with front and (*f*) with both legs, (*g*) losing tail and (*h*) adult.

the mammal a much better form of land vertebrate than the reptile. These animals had hairs instead of scales as well as many other advantages that we shall discuss later. With the mammal we reach the top of the tree, for to-day we are living in the age of the mammals, of which Man himself is the most highly developed. Man did not descend from the monkey, and certainly neither Darwin in his famous *Origin of Species*, nor the evolutionists after him, ever suggested that this was so. Darwin's idea was that Man and the apes had a common ancestor, and this is very different from the popular fallacy that is revived periodically.

Our tree of evolution has given us a very useful classification of the Animal Kingdom—and that is exactly what naturalists have done with the 700,000 species of animals known to science. They have grouped them from the highest form down to the simplest.

THE TWO GREAT DIVISIONS

The Animal Kingdom is divided into two great *Phyla*—the Vertebrates (back-boned) and Invertebrates (back-boneless). Each of these is subdivided into *Classes*, such as Mammals, Birds, and Fishes. The classes are divided into *Orders*, such as Carnivora or "flesh-eaters" and Rodents or "gnawers". Each order again is divided into *Families*, such as the *Felidae*, or cat family; the *Canidae*, or dog family. Each Family into *Genera*, such as the genus *Felis* or true cats; and *Passer*, the true sparrows. Finally, each Genus, or smallest of these groups, is split into *Species*, each species bearing the generic name in addition to its specific name—for example, *Felis domesticus*, the household cat. In this way in an orderly manner the whole Animal Kingdom is classified without any confusion.

We do not find life in such an orderly arrangement in the countryside, however, for here the species are all mixed up, according to the type of living most suitable for them.

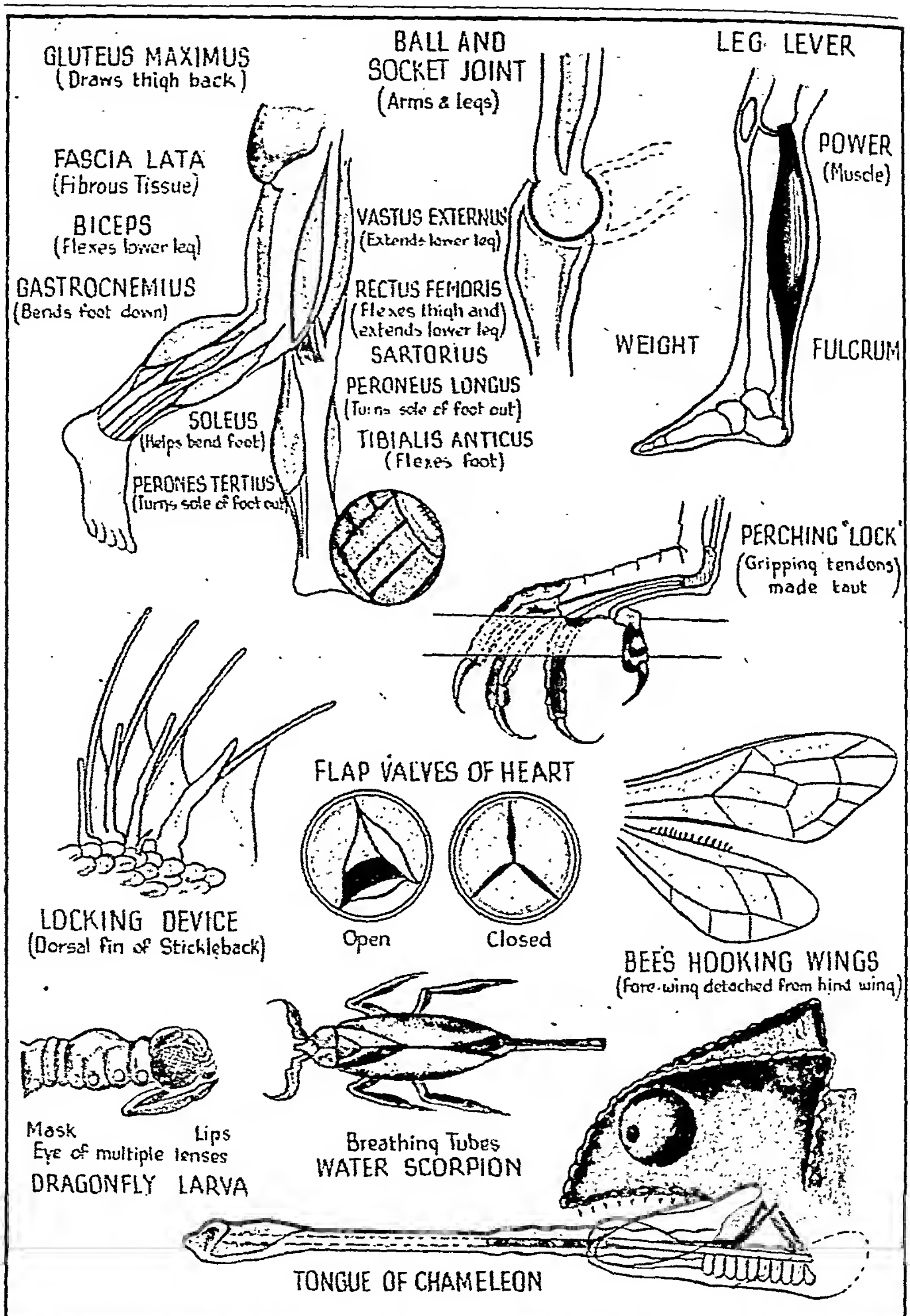
This study of distribution, called Ecology, does not enter into classification, which, as we have seen is based on animals' structure—how they are made—and not on habitats, or living-places.

Such a system of classification is to be preferred, for any system of classification must be universal and capable of being used by naturalists in all parts of the world.

As all nations do not speak the same language Latin names are used by common agreement. A Latin name tells us more than the popular name, as, for example, in the case of *Felis leo* and *Felis domesticus*, from which we see at a glance that the mighty lion must be related to the cat, since both belong to the same genus, *Felis*. On the other hand, when we consider the house-sparrow and the hedge-sparrow we find that one is called *Passer domesticus* and the other *Accentor modularis*, it is at once evident that, despite their popular names, these two sparrows are really not related at all. Actually, the house-sparrow is a true sparrow—otherwise he would not belong to the genus *Passer*—whilst the hedge-sparrow is really a warbler, a very different bird. Another example: the Latin name at once shows us that the tree-sparrow, *Passer monatanus*, is a true sparrow.

FORMS OF REPRODUCTION

The addition of a third part to the scientific name means a variety or sub-species. For example, *Troglodytes troglodytes zetaludicus*, the Shetland wren, is merely an insular variety of our common Jenny Wren, which we call *Troglodytes troglodytes troglodytes*. Here the repetition of the specific name is



Some marvellous mechanical devices used by nature. Man indeed, cannot rival nature with his finest machines, for while nature's machines are quite as ingenious as Man's, they have the great advantage of being less likely to go wrong. Moreover, when they do go wrong, they are self-repairing.

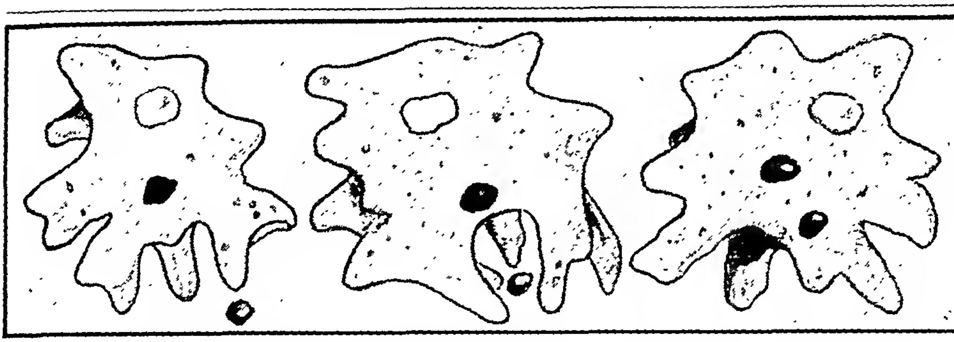


Fig. 1. The Amoeba, a simple unicellular organism found in ponds, feeds by engulfing food.

merely to assure us that it is the typical species and not a variety.

Animals normally breed only with their own species. For example, in dogs, Retrievers may cross with Airedales, and Setters, as these are all varieties of one species, the Dog. Only occasionally has a dog been mated with a wolf, or a fox.

The simple, one-celled animals, at the bottom of the tree of evolution in the classification of the Animal World may easily be seen with a small microscope in almost any sample from the muddy bottom of some pond or ditch. They appear as specks of brownish shapeless jelly-like matter, slowly moving by expanding and contracting (Fig. 1).

These *Amoebae*, the simplest of animals, have no definite shape as have the higher animals. They are seldom more than half a millimetre in diameter and move in a primitive way, appearing to flow along by pushing a bit of the body out on whichever side they wish to move, at the same time drawing in the opposite side. When feeding they simply engulf their food by flowing the body around it thus ingesting, or absorbing, it (Fig. 1).

In order to prevent its protoplasm, or living matter, from flowing idly away, the *Amoeba* is protected by a skin wall. In the main part of the body is a dark spot. This is the nucleus or centre of life—the primitive forerunner of the brain.

There are two spaces inside the *Amoeba*. One is a transparent space periodically expanding and contracting, and called the "contractile vacuole", or excretory organ, by means of which waste matter is got rid of. The other is the "food vacuole" where the tiny creature holds and digests its food.

In reproducing, the creature merely divides, the nucleus splitting first and the protoplasm joining each half, so

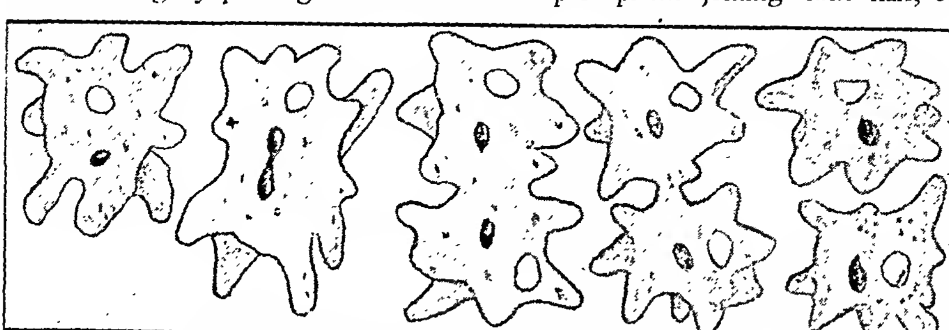


Fig. 2. How the Amoeba reproduces by simple cell division.

that one *Amoeba* divides into two new *Amoebae* (Fig. 2). Normally, therefore, the creature never dies.

Lest its water-habitat should dry up, the *Amoeba* can "encyst", or remain in a dried form until returning moisture brings back its natural conditions. Encysted *Amoebae* may be revived from stalks of wheat if placed in a glass of water and left for a few days.

THE REPRODUCTIVE CELL

In the life of the *Amoeba* we see the beginnings of animal life, but other animals are considerably more complex. For instance, the higher animals cannot split into two for reproduction because they have more than one type of cell to reproduce. Hence they have produced a special type of reproductive cell from which can grow all the other special types of cells that go to form one of the higher animals, whether it be a frog or a bird, a snake or man. This germ cell, the most wonderful thing Nature has produced, is the basis of sex—the reproductive method of the higher animals—and the cells are handed down from generation to generation with the factors of inheritance contained in them. The *Amoeba* has no sex—it is asexual; that is to say, there are no such thing as male or female *Amoebae*. Many of the very lowly animals are without sex, but earth-worms are hermaphroditic, that is, each has both male and female sexual organs, and mating does occur.

The germ cells of the higher animals are much more complex and exhausting to produce. The female produces what are called the ova or eggs, and the male the fertilising element or sperm, which on contact with the ovum brings life to it, and commences the growth of the new offspring.

In the higher "viviparous" animals—those that bear their young alive—the egg is very small and the embryo, or offspring, held inside the body of the female is fed from the mother animal's blood-stream until ready for birth. It is a miniature replica of the species, able to breathe and take in food.

With the notable exception of the duck-bill and the echidna or porcupine ant-eater, nearly all the mammals—or four-footed hairy animals—and many of the fishes give birth to living young. With many creatures—such as birds and insects, most of the reptiles, and many of the fishes—the fertilised egg is passed out into the world and continues its development outside the mother. In such cases the egg is protected by an envelope or shell. At a trout-hatchery may be seen newly hatched fry, or young fish, with a large yolk-sac attached to them and from which they are still feeding. Careful inspection of the yolk of a hen's egg will show a tiny dark spot on the yolk. This is the "blastoderm", or embryo, that—had the egg been incubated—would have fed on the yolk until the chick was ready to break through the shell.

LIVING EXAMPLES OF EVOLUTION

Living examples of the stages of evolution—the story of how mankind and all the other animals reached their present conditions—may be seen around us in the world to-day. We have the specks of protoplasm, the one-celled animals, and those of many and specialised cells. We have animals with backbones; the fishes and the reptiles; and examples of those that learned to fly. Finally, we have the higher animals—descendants of those mammals from which the apes and mankind arose. Tracing these sources backwards by means of the "testimony of the rocks", by studying the fossilised remains of prehistoric life and comparing them with the life-histories of creatures living

to-day, we gather the facts about the story of life. In gathering these facts, geologists—students of the rocks—and zoologists—students of animals—have worked together for a common end.

The existence of fossils proves many things. We find fossil fishes and marine shells in the coal measures of our deep mines, as well as on the top of Snowdon and in the high Alps. From the former we learn that these rocks once below the sea have been covered by other strata since Carboniferous times. From the latter we learn that the Snowdonia range was once a sea beach that has been raised to its present high level.

Fossils of reptiles that had learned to fly—such as the pterodactyl—and of primitive birds—such as the archaeopteryxus, half-reptile and half-bird—may be seen in most of our museums. Here, too, may be seen the bones of the Mammoth, of the Plesiosauriaus, and of other great animals of the past. By noting the rocks in which the fossils are found, the geologist is enabled to name the period during which any extinct animal lived. He is able to tell us, for instance, that 4,000,000 years or more constitute the Age during which the mammals, or animals that suckle their young, have been dominant in the animal world; that before them the dominant creatures were the great reptiles. That earlier still there was a period when the most important animal life consisted of fishes and amphibia. That before these was an age when no back-boned or vertebrate animals had appeared, when life consisted mostly of giant sea-scorpions and trilobites. These latter—so named because their bodies consisted of three lobes or divisions—were curious crustaceans—that spent their time crawling or swimming slowly along the bottom of the sea.

In the earlier rocks there are but few remains of animal life because most of the living creatures of those days were soft-bodied jelly fish and microscopic creatures such as those forming the green scum of ponds. Later, some of these creatures had shells that dropped to the bottom of the sea as they died, and thus built up our chalk cliffs and Downs. In the earliest rocks of all there is no trace of life.

Although the rocks show us that one "Age" followed another, all the types of animals of the previous Age did not die out immediately—nor, in fact, did one geological age follow sharply on another. For instance, even to-day, there are "living fossils", or representatives of those creatures that were dominant in ages of the past. Living representatives of the trilobites of early times (see Chapter 19) are the curious "King-crabs" or

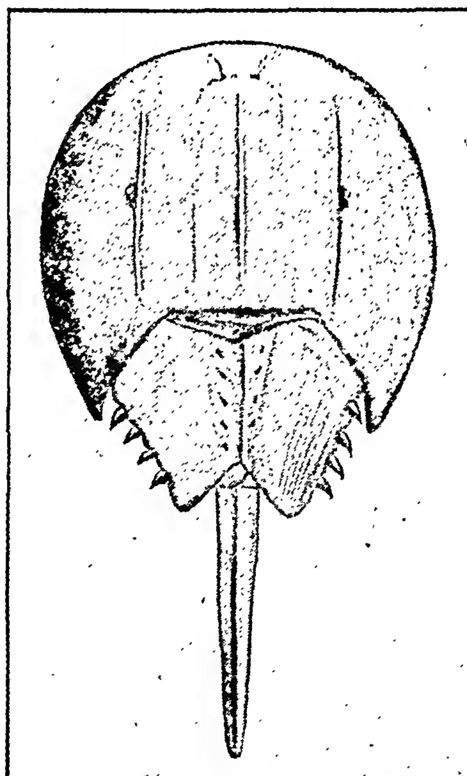


Fig. 3. The Pacific King Crab, a living survival of the prehistoric trilobites.

Fig. 4. An artist's impression of the Irish Elk, a huge animal that survived in Ireland until historical times. This great animal was a distant relative of our modern Fallow deer.

"horse-shoe crabs" of the Pacific shores (Fig. 3). The giant reptiles are represented by the giant Komodo Dragons, of the Dutch East Indies, and by the giant marine Iguanas of the Galapagos Islands off the west coast of South America. Incidentally, the Ecuador Government is hoping to turn these islands into an international nature sanctuary because of the rare wild life there.

WHY "LIVING FOSSILS" SURVIVE

Such "living fossils" have survived because their haunts have been cut off from the rest of the world, so that the more successful predatory creatures have not been able to enter their lands and exterminate them. It was for the same reason that the giant Irish elk (Fig. 4) which was really a relative of the fallow deer of our parks to-day, survived in Ireland until early historical times. This mighty beast was driven out of England by the coming of the so-called Sabre-toothed Tiger (Fig. 5), and the lion. As the land bridge between Galloway and Ireland was severed long before the land bridge between England and the Continent, the Sabre-toothed hunters could not cross to hunt the giant deer of Ireland. It was not until early Man became a better hunter that the deer was exterminated in Ireland. Remains of this great deer, which stood up to 6 ft. tall at the shoulders with a great head of antlers having a spread of 12 ft., are sometimes dug up from the old peat bogs of Ireland. It was a central European beast, too, and was probably first evolved in England, whence it spread to the South-West of Scotland, and thence into Ireland.

From the existence of ancient animal types in Australia and elsewhere, we see

how important it is that an animal should be protected from its would-be enemies. In addition, there must be suitable living conditions for it to survive. That is one reason why it seems difficult to credit the theories that the "Loch Ness Monster" and the "sea-serpent" are Plesiosaurians or Ichthyosaurians—descendants of the prehistoric reptiles of Cretaceous and Jurassic times.

IS THERE A SEA-SERPENT?

Some sea-serpents may be optical illusions or may be due to an imaginative mind after seeing the great Giant Squid or the Ribbon Fish, or some even commoner sea creature on one of its rare visits to the surface from the depths of the ocean (Fig. 6). It is only necessary to start a "monster" hunt in some lake or bay to get reports from would-be eye witnesses—as, for instance, the bather who a short time ago clearly described a great grey Atlantic seal as a monster! It is significant that no monster has ever yet been found that cannot be described by science.

An important associate of evolution is heredity, first worked out by the monk Mendel amongst the sweet peas in his monastery garden. It is through a knowledge of the laws of heredity that we are able to speed up Evolution, as it were. By a process of selection we are able to produce the types of animals and plants we desire for the farm or the garden. Evolution is going on slowly in the wild to-day as a selection, by the survival of the fittest. Those creatures that are best fitted to meet the demands of the circumstances under which they live survive and breed, whilst the unsuitable ones die off.

The workings of the laws of heredity

Fig. 5. The terrible Sabre-Toothed Tiger. This beast drove the Irish Elk out of Britain.

in the fulfilment of evolution are well shown in the story of the horse. Our horses of to-day developed from a little hare-like ancestor with many toes, called *Eohippus*, to the modern creature that runs on one enlarged toe on each foot (Fig. 7). The greatest example, however, is the story of the rise of Man from an ape-like jungle ancestor to an upright creature that can talk, manipulate the fingers of his hands, laugh, preserve his own health by curing disease, and do other things that cannot be done by any other creature in the animal world.

Instead of taking Mendel's garden peas with which to illustrate the working of heredity, let us consider the effect of heredity on the domestic cat, a subject that Mrs. Bisbee, one of the lecturers at Liverpool University, has made her special line of scientific research.

Mendel's laws show that when two pure-bred animals or plants of different varieties are crossed, half the offspring is pure-bred and half hybrid (Fig. 8). Pure offspring mated with pure will breed pure, but hybrids mated with their like will produce their like and also "throw-backs" of their parent types. By selecting the characters and pedigree of each parent—and thus knowing the proportions of pure and hybrid offspring that will result—plants or animals can be bred to certain desired ends.

In crossing these types it is found that some characteristics are dominant over others in the offspring. For example, tallness is dominant over dwarfness, black over white, and so on. In the case of the common tabby cat, there are three main types. The "Blotched" have bars or stripes on the sides, and a noticeable

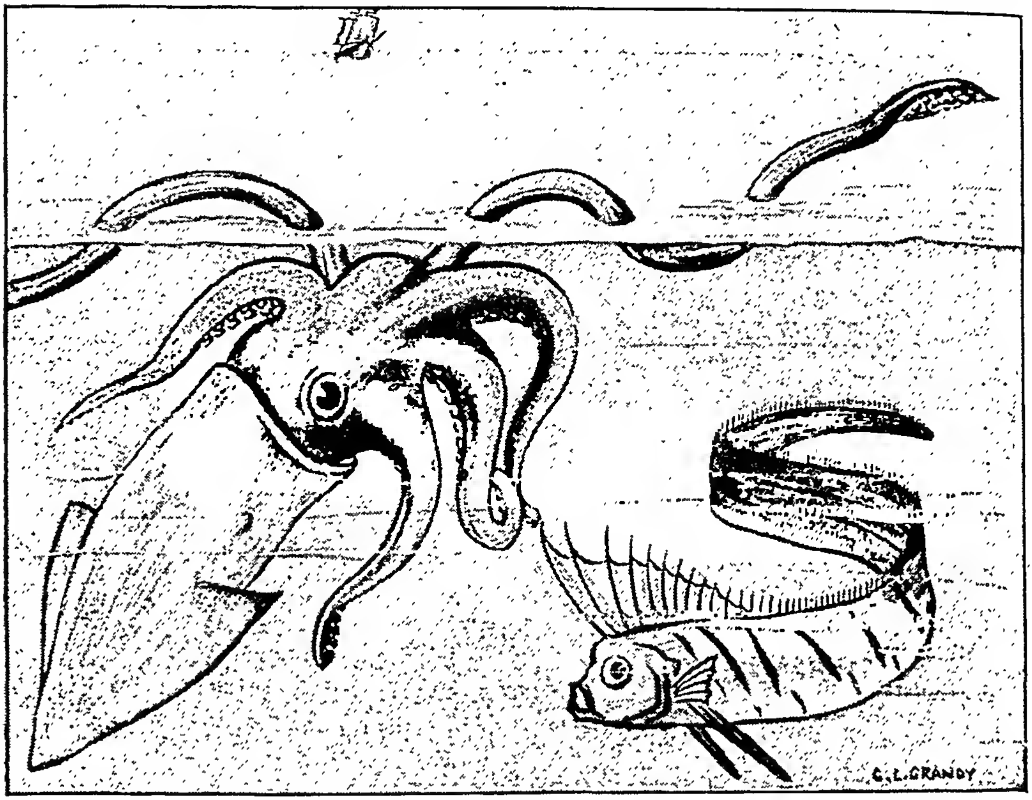


Fig. 6. How the legend of the Sea Serpent might arise. Both the Giant Squid (left) and the Ribbon Fish (right) might be mistaken for one when swimming near the surface.

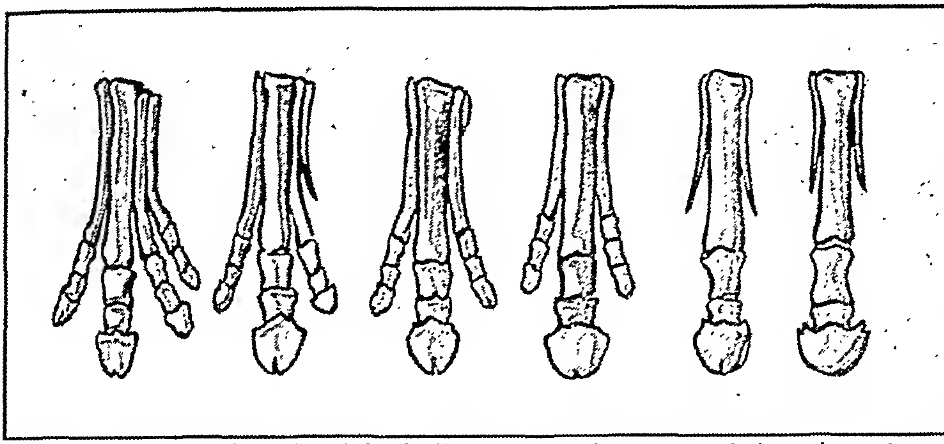


Fig. 7. The evolution of the Horse's hoof. The Horse's earliest ancestor had toes but as it used the middle toe more, the others gradually became atrophied, and the modern horse's hoof evolved.

whirl of them round the groin. The "Striped" variety are similar but without the whirl or blotching at the groin. The "Lined Type" have finer and closer stripes on their sides. If two pure-bred Blotched tabbies are mated, all their kittens are Blotched. If a pure Blotched female is mated with a pure Striped tom, all the kittens are Striped, for the Striped variety is dominant over the Blotched. Should this Striped tom not have been pure bred—that is, say he had a Blotched tabby parent mated with a Striped tabby, the result being Striped kittens owing to the dominance of the Striped form—then half his kittens will be Striped and half

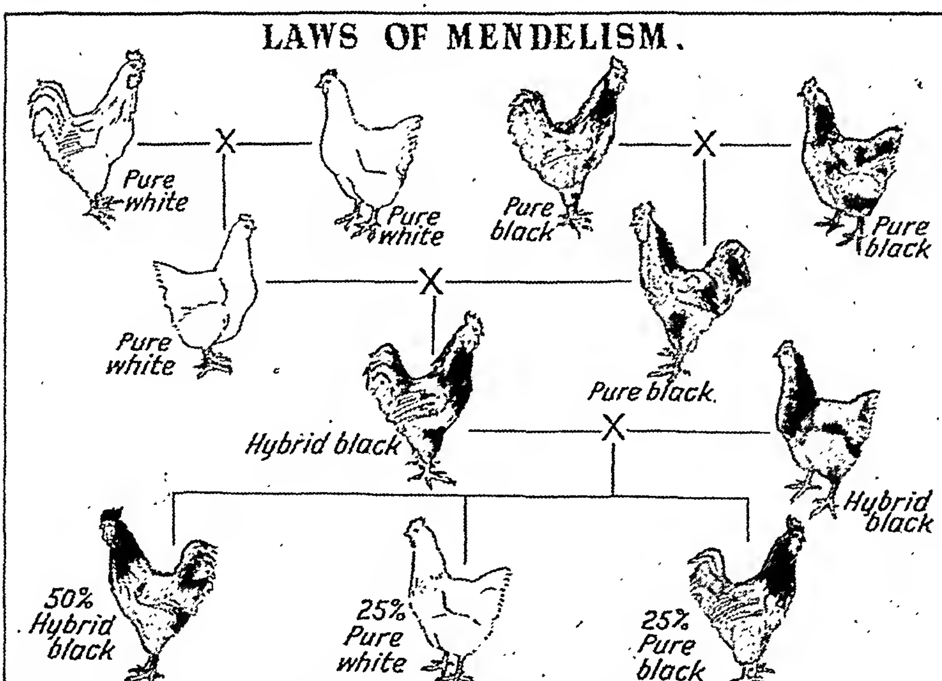


Fig. 8. The principles of the Mendelian theory of heredity illustrated by breeding of hens (see text).

The Koala Bear is found in South East Australia, where it is popularly known as the Native Sloth. A marsupial belonging to the wombat family, it is two feet long and a vegetarian.

tortoise-shell kitten from yellow and black parents is nearly always a female, but any toms produced are normally black, or yellow, or blotched a "marmalade" colour. A tortoise-shell tom is a rare freak due to an accidental transmission of the "chromosomes"—the wonderful bodies in the nuclei of cells that carry the powers of inheritance.

The theory is that black toms probably have but one "dose" of chromosomes of blackness to pass on to their offspring, whilst female black cats have two doses. Yellow and black toms pass on their colour characteristics to their female offspring only, so that any tom kittens in these crossings receive colour chromosomes from their mothers only, but daughters receive both from mother and father. Thus, a tom-kitten may get only yellow chromosomes or black ones, whereas a female kitten gets both, hence her tortoise-shell colour.

Blotched. All the kittens of a pure "Lined" tabby mated to a pure "Striped" tabby will be Lined, however, for the Lined variety is dominant over the Striped. If an impure Lined tabby is mated, half the kittens may be a hybrid variety of impure Lined, and half pure Striped.

The heredity powers of cats have been studied much further than this, of course, for the mating of hybrids brings out more recessive characters that lie dormant in their parents. For instance, a blue cat mated with a cream cat breeds dark tortoise-shell kittens, as does the mating of a blue cat with a yellow cat. The

FREAK HEREDITY IN CATS

The rare freak of a tortoise-shell tom may thus be accounted for when a kitten gets from its parents two doses of colour chromosomes instead of one. In the normal dividing of the bunch of chromosomes in cell-division that makes for reproduction these two may fail to separate. Contrary to the general rule of heredity, white cats are dominant over black cats, and a white cat mated to

a black one should have white young.

These experiments relate only to colour, but there are other characteristics of greater importance, that are subject to the laws of heredity. Through these we see that evolution is going on in the world to-day, as in the past. Animals and plants are being forced to change their habits the better to find their food, or their mates, in changed environments. This continued practice of the changed habits over many generations is the cause of the alteration of the structure to meet the new conditions, all of which is inherited under definite laws.

In the early life of the embryo of most animals, too, the story of its evolution from its more primitive ancestors is recapitulated in structure or habit. Examples are found in the tadpole-like free-swimming larva that develops into the sedentary, bag-like sea-squirt of the rocks; the free-swimming larval stages of crabs and oysters; or—to turn to the vegetable kingdom—the gorse that has prickly needles in adult life but shows true leaves in its early stage.

HEREDITY AND EVOLUTION

Freaks, or "sports" as they are called, sometimes occur in offspring—one in 100,000 is the average with the banana fly, *Drosphila*. As with freak goldfish, this fly may breed true to form, but this is exceptional. These new varieties, inheriting very slowly their new habits and adaptations, gradually become so different from their original type that they will not breed except with their own kind. Thus new varieties become new species. We can trace the evolution of a creature not only in embryology—the early life history—but in fossil remains. In North West America, for instance, are some wonderful examples of different rocks, lying layer on layer as they had silted a river and buried the animals killed by the spates over successive periods. In these rocks are fossils that tell the story of both the horse and the camel. Here we see the gradual evolution of these animals from their early five-toed ancestors that were little bigger than foxes.

The word "animals" includes also insects with their hard outer skins of chitin; birds, with their feathers; reptiles, with scales; fishes, with fins; and mammals, with hair, which suckle their young.

At the head of the animal world we place man—a mammal, descended from an ape-like ancestor. At the time when the great reptiles were competing with the mammals for the mastery of the Earth, this creature took to a life in the trees and remained there until later Ice Ages killed off the giant reptiles.

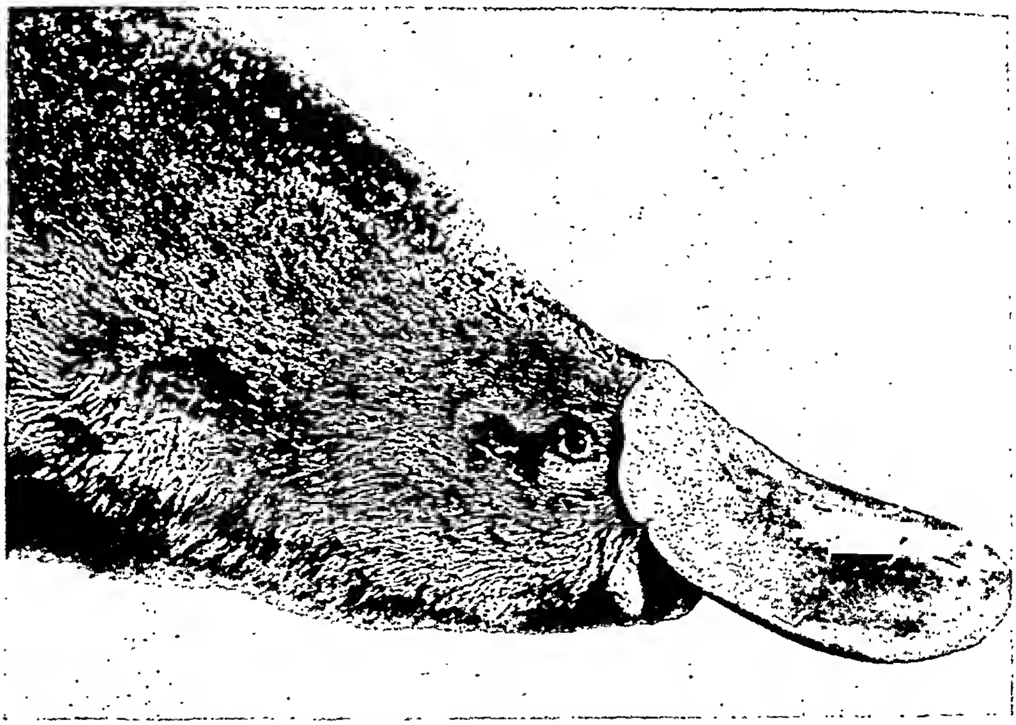
BEETLES AND CRUSTACEANS

Some animals—such as fishes, reptiles, birds, and mammals—have a backbone or internal skeleton. Others—such as insects—have a hard external skeleton. The lowly marine and fresh-water creatures have soft bodies. The reason for these differences is largely a matter of growth in the particular environment where the various creatures must live. The soft-bodied sea creatures have their weight very largely supported by water. Insects—for example, beetles—and crustaceans—crabs and the like—have a good protection on land in their hard skin. There is the disadvantage that when they wish to grow they have no room to do so unless they split the skin and climb out and grow a new one as the crab does. On the other hand, the beetle confines its growing to its grub stage. The more highly developed animals could not afford to do this often, so they have their muscles attached to an internal skeleton. This holds them in place, but does not hamper growth.

At one time "warm-blooded" was a

term used to describe the mammals and birds, and "cold-blooded" the reptiles and fishes, but these expressions are now out of place. The real difference is that the mammals and birds, being more highly developed, cannot stand great changes of temperature. Therefore, they are "homothermic", or constant-temperatured, and because they rarely go much above or below an average they are liable to die from exposure under severe conditions such as sunstroke in the tropics. On the other hand, the more primitive fishes and reptiles can withstand great changes. In cold weather their body temperature drops and in hot weather it rises. The garden goldfish may be frozen into a solid block of ice in the pond in winter, but he will thaw out none the worse for his cold spell. The cold-blooded, or "changing-temperature", animals that are able to adapt temperature to their surroundings, are less active than birds and mammals and so create less body-heat and seem colder than the others.

Now let us look at some of the great mammal group, or phylum, to which we humans belong—the four-footed, fur-bearing animals that suckle their young. This group evolved as a branch of the reptiles by changing their coat of scales to one of hairs for greater warmth. At the lowest end of the scale are the primitive duck-bill *platypus* and the *echidna* ant-eater of Australia and New Guinea (Fig. 9). So low in the scale are they that they lay eggs like the reptiles. Only a little higher in the scale are the marsupials—such as the Australian Kangaroo, the Tasmanian Devil, and the American opossums—that nourish their young in pouches in their bodies. A little higher are the toothless insect-eaters—such as the sloths—that live upside-down, hanging from



The curious Australian Duckmole, or Duck-Billed Platypus. It lays eggs like a reptile, suckles its young like a mammal, burrows like a rodent, and has a duck's bill and webbed feet.

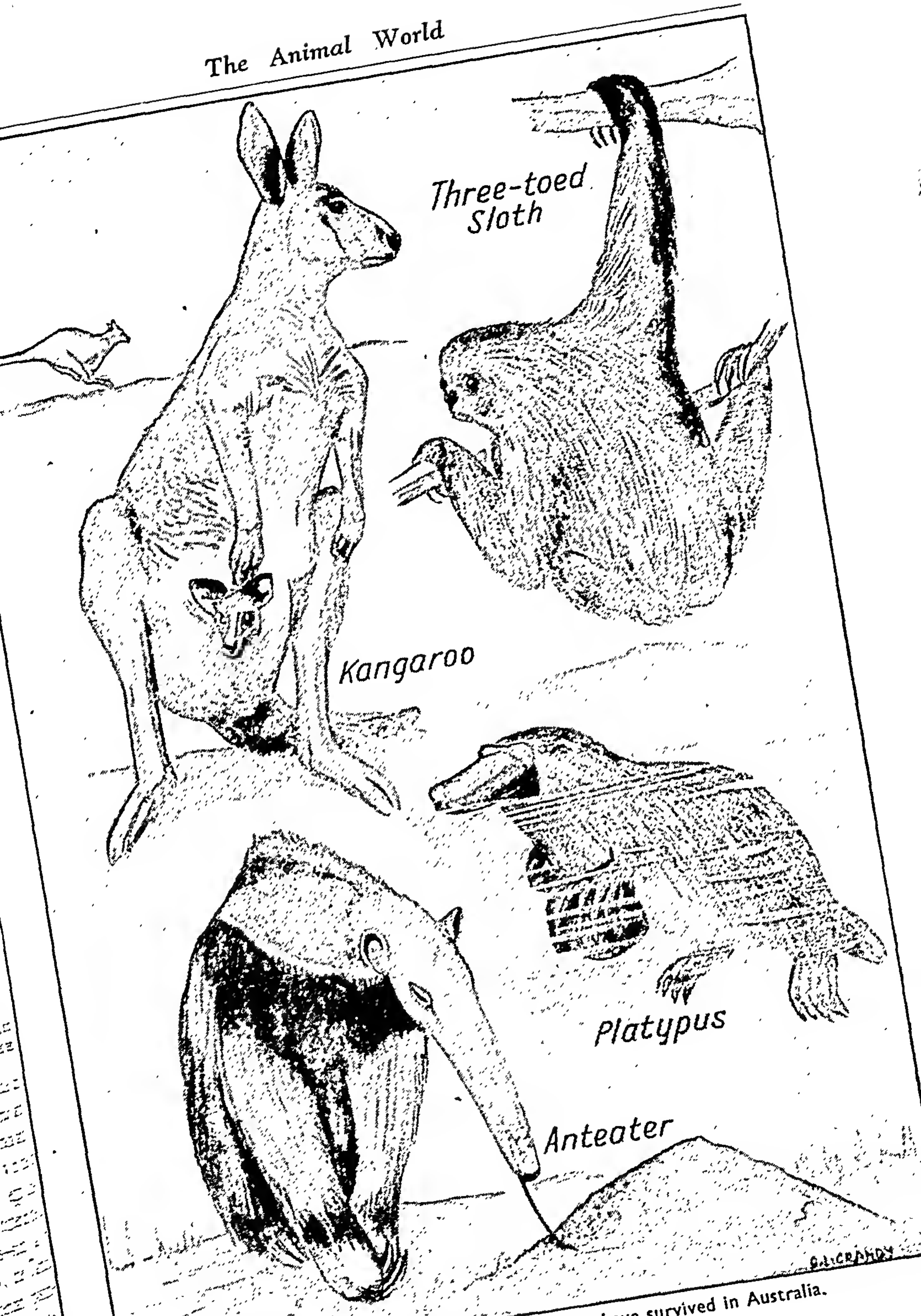


Fig. 9. Some of the curious animals that have survived in Australia.

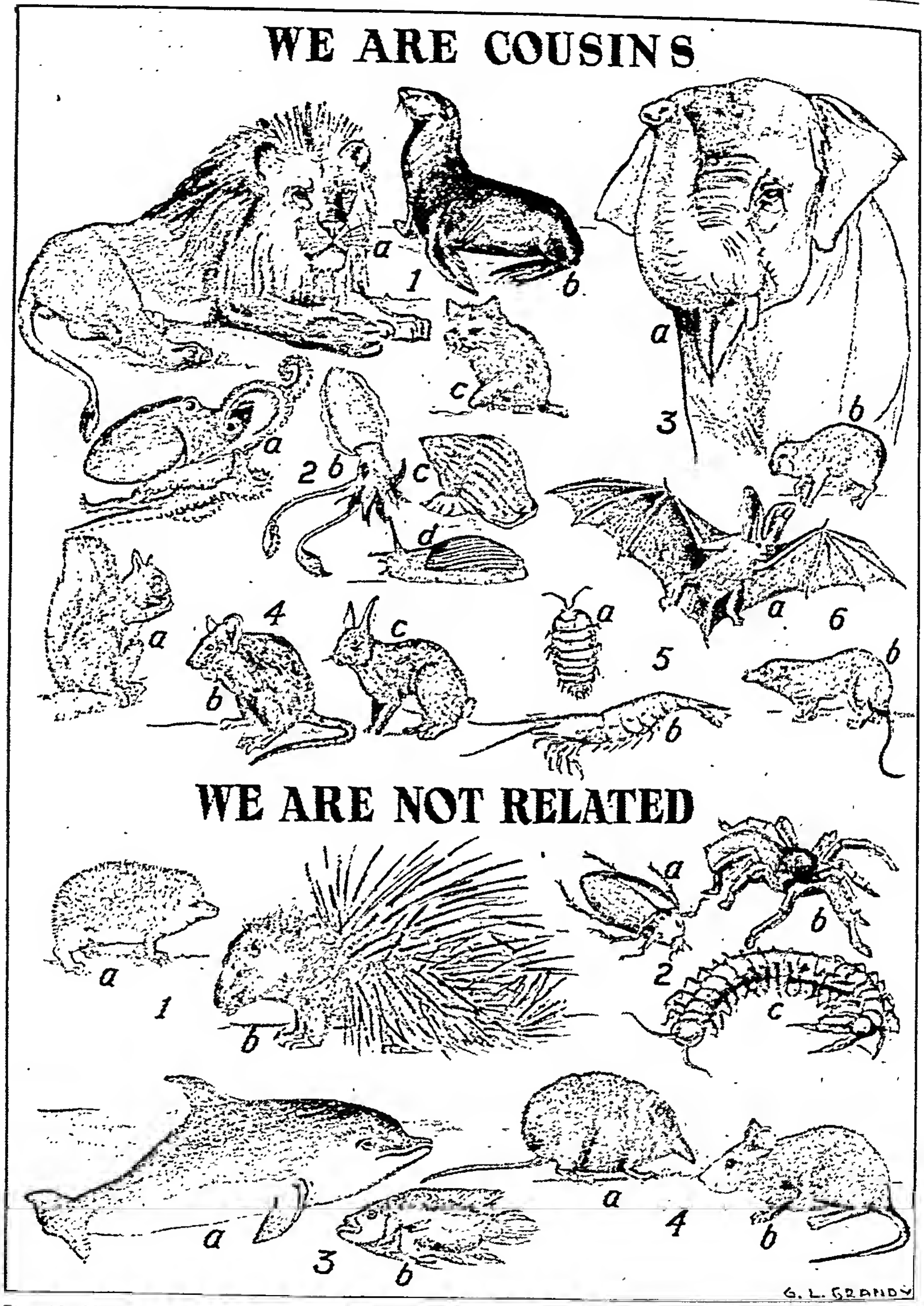


Fig. 10. WE ARE COUSINS. 1, (*a*) Lion, (*b*) Sea Lion, (*c*) Cat. 2, (*a*) Octopus, (*b*) Cuttlefish, (*c*) Whelk, (*d*) Slug. 3, (*a*) Elephant, (*b*) Hyrax. 4, (*a*) Squirrel, (*b*) Rat, (*c*) Rabbit. 5, (*a*) Wood louse, (*b*) Shrimp. 6, (*a*) Bat, (*b*) Shrew. WE ARE NOT RELATED. 1, (*a*) Hedgehog, (*b*) Porcupine. 2, (*a*) Beetle, (*b*) Spider, (*c*) Centipede. 3, (*a*) Dolphin, (*b*) Fish. 4, (*a*) Shrew, (*b*) Mouse.

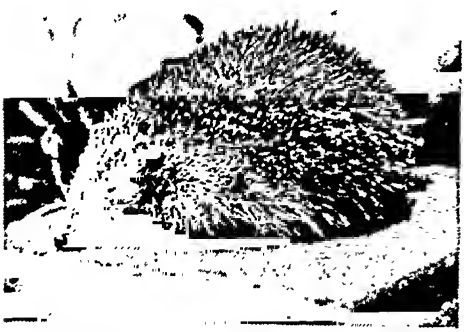
the trees of the dense Amazon jungles.

At the top of the scale are the monkeys and apes between which there are many differences. The most noticeable of these is that the former have tails, and the latter—exemplified by the gorilla and chimpanzee—are tail-less. With many other animals the differences are such that often cause their relationship to be overlooked, until their fundamental structures are closely examined, as in the case of the hippopotamus—a close relative of the pig—and the mighty elephant—a close relative of the little rock-hyrax—the "coney" of the Bible. The most noticeable differences are due to the widely different habits of their ancestors as they roamed the Earth in search of safer and less competitive homes.

CLASSIFYING ANIMALS

Exactly as two closely-related animals may evolve quite different appearances due to their adopting quite different environments, so two distantly-related creatures may evolve similar organs and structures if their environment requires them to guard against similar enemies, or to overcome similar difficulties of feeding.

It is by studying the structure of various animals that we are able to classify them correctly (*Fig.* 10). For example, shrews burrowing in the



The Hedgehog, a familiar denizen of the countryside. The Hedgehog hibernates throughout the winter, and lives on small vermin.

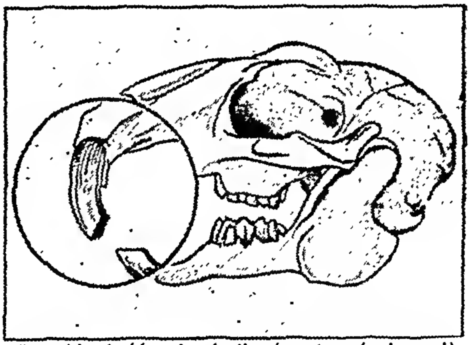


Fig. 11. A Hare's skull, showing (enlarged) the sharp and pointed edge of its incisors.

ground, at first look like mice, but on closer inspection we see they have long snouts and tiny insect-eating teeth, whereas mice are rodents with large front-eating teeth, or incisors, for gnawing roots and vegetables. They have no eye-teeth nor canines, as they have no flesh to tear. Similarly, we see that bats, often called "flittermice" in error, are but flying relatives of the shrews, for they feed on insects—they are *not* "mice with wings". The hedgehog with his protective coat of prickles is an insectivore. Although the porcupine may seem a close relative because of his prickles, examination of his teeth shows him to be a relative of the rat, mouse, squirrel, rabbit, hare and beaver, for he has the large incisors of the Rodents. These big incisors are like chisels, and have a soft layer backed by a hard enamel so that the soft side wears down more quickly than the hard, thus maintaining a sharp edge (Fig. 11). Moreover, these front teeth grow rapidly to keep pace with the constant wear to which they are subjected. If one tooth is broken and the animal cannot feed naturally, the remaining teeth grow out of all proportion. Rabbits have been killed by the incisor teeth growing out of the mouth, over the head and into the skull again.

Quite a number of the mammals hibernate for the winter in very cold

The Sea Lion, one of the few mammals that have returned to live in the sea. It is one of two seals that have external ears.

regions, usually laying up a store of fat in their bodies by extensive autumn feeding. By a concentration of bromine in the brain they remain dormant in their winter sleep, during which only the ventricles of the heart beat very slowly until the warm weather of spring arouses them. In the mild climate of Britain, few mammals hibernate properly. Shrews and squirrels are abroad all winter, and any mild spell brings forth bats and even hedgehogs, badgers, and moles.

WHALES AND SEALS

Some of the mammals went back to the sea because the struggle for existence was too hard on land. Amongst these are the whales, or cetaceans, that have grown to be the biggest animals the Earth has ever known. The Blue Whale, or Sibbald's Rorqual, sometimes reaches 100 ft. in length. Whales have horizontal tails, not vertical ones like fish. This is because the whale is an air-breather with lungs, and in addition to diving to catch its food, it must also be able to rise quickly to the surface to breathe. The fishes need only a tail to force them through the water in pursuit of their food.

Porpoises and killer whales have sharp teeth because they must catch large fish whole for their food, but the baleen whales—like the big Greenland whale that feeds on small crustaceans—have the mouth cavity draped with huge plates of baleen—the so-called "whalebone". This acts as a sieve, draining the food after a mouthful of water is squeezed through by the whale pressing its tongue against the roof of its mouth. Although its mouth is so large that a man can well stand upright in it, the throat is so small that it cannot swallow anything larger than a cuttlefish.

As with fishes and minute swimming creatures, the whale needs no legs to support its body in the sea, so it developed its limbs into flippers and with these it propels itself. When a whale is stranded on the shore, however, it dies from the great weight of its body crushing in its chest, for it has no limbs to support it.

Another mammal that went back to the sea was the seal, but it is not related to the whales at all, having been evolved much more recently. Thus it can still shuffle along the rocks where it breeds, while its teeth shows it to be a carnivore or flesh-eater, related to the cats and foxes and otters.

We thus see that most of an animal's structure has a direct relationship to its environment, adaptations having been made to enable it to obtain its food, or to escape its enemies.

The colouring of animals arises from different causes and serves different purposes. The beautiful blue on the mandrill's face is an attraction used in courtship, being designed to attract the attention of the female.

On the other hand, the colouring of some animals is in the nature of

Although the Zebra's stripes make it conspicuous in captivity, in its natural surroundings of grassy plains and strong sunlight, they make a perfectly designed camouflage.

protective camouflage, causing the animal to resemble its surroundings and thus escape detection by its enemies. In the progress of evolution, those animals not so well camouflaged are most often caught, the others escaping being left to breed. In some cases colouring may also be designed to enable them more easily to catch their prey. A case in point is the tiger, whose stripes blend with the grasses and with the lights and shades of the jungles where it dwells. On the other hand, the lion's sandy-brown resembles the rocky plains and scrublands that are his haunts. The leopard's rings of spots break up his outline, so that he it not so easily noticed. The zebra's stripes are for a like purpose, breaking up his outline from a short distance, just as does the magpie's plumage in the light and shade of the tree tops.

Some of the lowly animals, such as frogs and chameleons, are able to control their pigment cells and so change their colour according to change in the type of ground over which they are passing.

They become browner, yellower, or greener, according to the colour of their habitat.

There is a reason for everything in Nature. The cow, when lying down, sinks fore-feet first, and rises first on its fore-feet, but the horse goes down hind-feet first, and rises on its fore-feet first. The reason for this difference is that the wild oxen ancestors of the

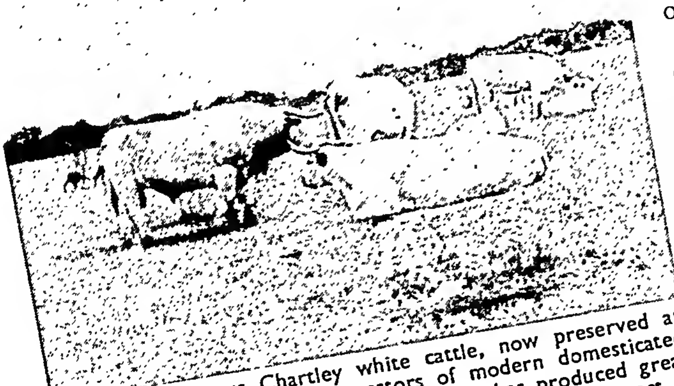
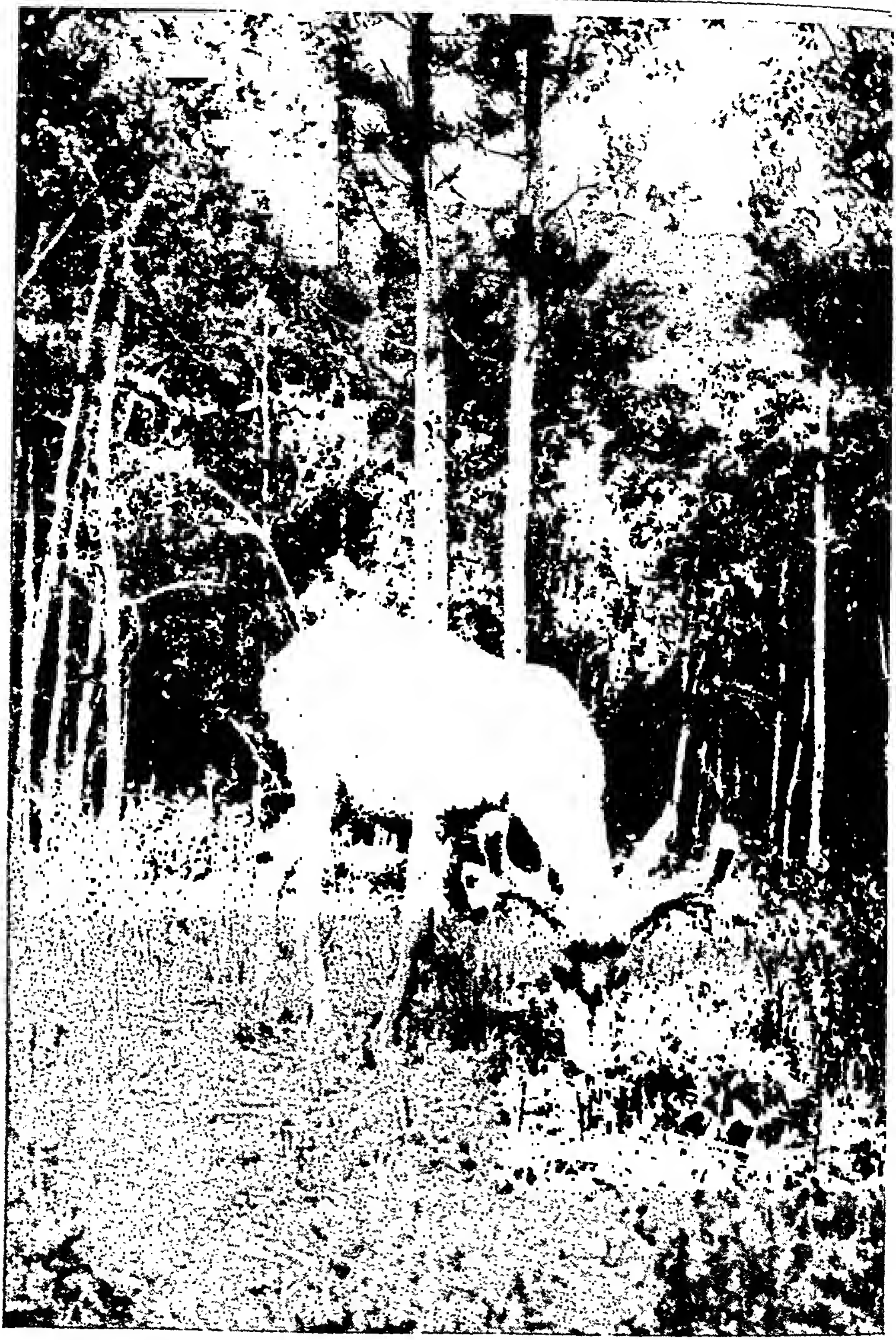


Fig. 12. The famous Chartley white cattle, now preserved at Whipsnade. They are the ancestors of modern domesticated cattle. Modern cattle breeding, however, has produced great changes. Oxen are now smaller, heavier and more compact.



A fallow deer showing the velvet on its antlers. Deer shed their antlers once a year.

domestic cattle—now typified in the famous Chillingham herd of park cattle, or the Chartley wild cattle (Fig. 12) (from Chartley Park in Staffordshire) at Whipsnade—were forest-dwellers. Before lying down, and when rising, they had first to scan the district for potential enemies, keeping their heads low to see beneath the trees. Wild horses were dwellers on the plains where

regurgitate it and chew it in safety. Their stomachs became wonderfully adapted to enable them to carry out this process.

Stags, or male red deer, differ very much from cattle and antelopes in having antlers instead of horns on their heads. The difference is that the deers' antlers grow in summer and become fully developed by autumn, when the

Part of the main herd of bison in Buffalo National Park, Wainwright, Alberta. Bison once roamed the prairies of the American Middle West. Some years ago they were almost extinct but they are now protected and are once again increasing rapidly in number.

beasts of prey stalked from afar. They had to keep their heads high to scan the landscape.

Then again, there are the ruminants—the deer and oxen—that chew the cud because their ancestors were woodland dwellers and could not fight their many foes on the grassy plains. When the coast was clear, they stole out to graze, gulping down as much food as they could ...r in the time, then retreating to the ...s where they could

stags battle with them for the hinds or females. After the battle has been decided the antlers are not required, so they are shed, and new ones grow the next year for the next rutting or mating season. The stag does not use its antlers to fight for its food, and only as a last resort against foes, for it normally runs for safety. On the other hand, the Ox has horns that are permanent structures and grow over a bony core. They are used as a

The Field Vole has a mixed diet. It can be recognised by its high-pitched angry cry.

permanent means of defence as well as for mating-fights, for oxen cannot run so swiftly as deer when enemies are at hand.

The ferocity of the wild buffalo is notorious amongst big-game hunters. Incidentally the North American Bison is often called a buffalo in error. The true buffaloes are the African, Australian, and Indian Buffaloes, whereas the bisons of North America and Europe, although different, are related to oxen. They are characterised by a large hump on the shoulders.

The former wild life of animals often provides many other reasons for their present habits and structures. Here are a few of the most interesting examples.

A dog turns round and round before lying down, because its ancestors, the wild dogs, had to flatten down the long grasses before they could make their bed. Sheep and goats have very small and narrow feet because their wild ancestors dwelt in precarious rocky places where footholds on the cliff sides were very small The giraffe has developed a long neck so that it can graze on the foliage of trees, for it lives on plains where so many animals graze that there would not be enough grass to feed them all.

The camel has a hump to store water, for its desert habitat forces it to live like the cactus, storing water when it can get it, never being sure of the next supply. The elephant has a long trunk so that it can drink from a pool or grasp bamboos and other food, for such a mighty animal with its cumbersome heavy skin very rarely lies or sits down in the wild. The badger has a thick skin and coarse hair to safeguard it from stings, for it feeds on the grubs and on the honey of bees and wasps.

Bats are not blind, as is generally supposed, for they can see in the dark. Most of them are really only twilight fliers, resting in the middle of the night. Their skinny wings are so sensitive that in the dark they quickly detect the presence of any twig or wire as they approach and thus are able to avoid it. An experiment has proved that even when blinded they can fly in a room entangled with threads, and yet avoid touching any of the threads. The Horsehoe Bat that lives in the limestone caves is so named because of a horse-shoe-shaped frill of very sensitive skin around the nose. This acts as a kind of wireless aerial that detects the presence of objects and thus enables the bat to fly on a pitch-dark night.

NATURE'S DANGER SIGNAL

The rabbit's white tail may be a danger signal to show baby bunnies the way home to the burrow when mother bolts in time of danger. This is the use of the white tail-feathers of the moorhen, and of the white rumps of deer and antelopes. An alternative American theory suggests that when a rabbit bolts to cover, the eye of its hunter is distracted from the young ones by the bobbing tail. When the rabbit has escaped down its burrow—or the moorhen has dived, or the deer has run quickly away—the hunter

remembers the young ones but then it is too late. They meanwhile have made their escape or—as in the case of many young shore birds, young deer, and hares or leverets—they have squatted flat so that their colour harmonises perfectly with their surroundings.

Another habit for the same purpose of attracting an enemy's attention from nest or young is practised by many birds, notably plovers and waders. Often they attempt to lure away the hunter by trailing a supposed damaged wing or leg, running along a little way ahead but never allowing themselves to be caught. Having lured the enemy so far from nest or from the young that he is not likely to find them again, the bird flies back.

The hare can run uphill faster than down, because its hind legs are longer. It does not burrow underground like a rabbit and so must run for safety. Indeed, leverets are born fully clothed and can run almost from birth, for they are exposed to many dangers in their open "form" in the fields. On the other hand, baby rabbits in the safety of the burrows are naked and blind at birth.

Some hunting animals, such as wolves and jackals, hunt in packs so that if one finds food, all can share it; their food is not as abundant nor so easily obtained as that of the lion and tiger and other solitary hunters.

Some creatures—the little field-voles for example—increase almost to a swarm when their food is abundant and when the weather suits them. Then their foes—the kestrels, owls, weasels and foxes—also increase and prey on them. Their numbers are reduced to normal again by disease epidemics. The Bureau of Animal Population at Oxford University has discovered much about these sudden increases in the numbers of voles, for they can be a serious menace to farmers by swarming over the fields and woodlands, causing widespread damage. By collecting records from field-naturalists over a number of years it has been found that these vole-plagues usually occur in cycles of about every fourth year. They seem to be the result of a natural wave of fertility reaching a peak, then declining, only to rise again.

Probably similar cycles of abundancy and scarcity affect other animals over longer periods of years and explain the changing animal populations naturalists have so long observed. One such case is that of the lemmings of Norway. These vole-like rodents increase out of all proportion to their normal numbers and finding there is not sufficient food in their usual haunts, they migrate in hordes across country, ultimately reaching the sea and drowning themselves

The Badger is one of the curious animals like the skunks and the pandas which reverse the usual colour design in having the under parts of their fur darker than the upper. This makes them conspicuous in daylight, but they are nocturnal animals.

in a futile attempt to swim across it.

The howler monkeys of the South American jungles are the rowdiest animals on Earth, their noise in concert excelling any other ear-splitting sound imaginable. By contrast the giraffe is not known to have any voice at all. Man is the only animal able to talk, smile, or cry. Neither the parrot nor the mynah really talk, for they only mimic meaningless words, just as starlings imitate other birds' notes.

"LAUGHING" ANIMALS

The laughing jackass kingfisher of Australia and the laughing hyena have "laughs" that are really calls. Even the intelligent monkey cannot see the humorous side of life, its grimaces not being real laughter. Crocodiles and seals may produce tears but not from the same weeping as human emotion, although many animals will become listless and lonely after the loss of a mate or affectionate owner.

Another illusion about monkeys may be mentioned. When we see them scratching they are not looking for fleas as is generally supposed. Monkeys are amongst the cleanest of animals and although most animals have their particular fleas—over 800 different species of flea are known to science—no flea has ever been found on a monkey in a wild state. The few fleas that do occur are derived from dirty surroundings or dirty owners. When searching one another's fur the monkeys are searching for any dirt or loose pieces of scurf or dry skin in their coats. They scratch to ease the irritation of their dense, woolly undercoats.

Ming, the young Giant Panda in the London Zoo. The Giant Panda is the rarest mammal in the world and only a few have been kept successfully in captivity. Pandas inhabit the bamboo-clad mountains on the borders of China and Tibet and were first seen alive by white men in 1929 when the Americans Theodore and Kermit Roosevelt shot one. Ming, who is a female, came to England in 1938.

Most mammals in cold climates produce denser undercoats for the winter, and lose the thicker coats in spring. For this reason furs from Arctic foxes and squirrels are more useful for the furriers than those of English animals. In Ireland, which is much milder in winter than England and Scotland, the mammals do not produce such thick coats, and whereas in the Highlands of Scotland, and on the Continent, stoats and hares turn white for the winter in order to harmonise with the snow and to keep warmer—white is not such a good conductor of heat as black—those in Ireland

Two Lesser Pandas in the London Zoo. The Lesser Panda, which comes from India, is no relation to the Giant Panda ; it is in fact, a member of the Racoon family.

do not grow white coats for the winter.

The mammals in their evolution from the reptiles changed their scales to hairs or fur so that they could keep warm when the cold spells descended on their haunts and the reptiles were driven further south, or finally exterminated. Some of the mammals retained their reptile-like scales, however, and we see such curios to-day in the pangolin of India and China and the armadillo of South America.

A visit to the Zoo surprises us by many unusual forms of mammals. However strange may be the animal's structure, though, there are two reasons for it. It may be a survival of the past that it is slowly losing—such is the case with the stripes of the baby tapir, the spots of the baby stag and lion, and the dark skin of the baby goldfish—or it may be an adaptation to its environment or for the purpose of obtaining its food.

Thus, when animals have to live under exactly similar conditions to earn a living they may develop similar structures although they are not at all related. On the other hand, animals that are closely related—"cousins" we might call them—may look very different if their environments are not alike.

THE AUSTRALIAN MARSUPIALS

The whale living in the sea has developed a horizontal tail, whereas the fishes living in similar haunts have vertical tails. In Australia there are two marsupials or pouch-bearing mammals, the kangaroo and the bandicoot, so closely related that we might call them "cousins". The kangaroo, however, has developed enormous hind legs, with first, second and third toes degenerated and the fourth and fifth enormously developed. This has come about because in the past the Kangaroo's ancestors have

The silver-furred Phalanger, one of an extensive family of pouched mammals found only in Australia and the far East. Phalangers are all vegetarians and superficially resemble squirrels.

for so long used these particular toes that they have inherited this great development. The fore-feet, however, are quite normal.

On the other hand, the bandicoot does not live as does the kangaroo. It has normal hind feet, but because it burrows extensively, it has specialised fore-paws in which the second and third toes have degenerated and the others increased enormously in size and strength, as is the case with the kangaroo's hind feet. The jerboa and the jumping hare of Africa are not related to the kangaroo, but they have developed similarly large hind legs because they move by a progression of hops.

The habits of the mammals are as interesting as their structures, although it is only in modern times that much attention has been paid to them.

The movements of animals can be traced by marking them in various ways and then releasing them. Subsequently the animals are recaptured at some point far away from where they were released and the distance and direction covered is then ascertainable. In this way the migration of whales in Antarctica was studied by the *Discovery* by marking them with darts. In England, the migration of rats was studied from London by "tagging" their ears with numbered discs, much as cattle are tagged or as the Americans marked their elks for similar study. Of a number of rats labelled and released near Euston Station, London, one was caught six months later at Bradford, Yorkshire, 190 miles away, and others at Shrewsbury (153 miles), Matlock in Derbyshire (145 miles) and Wymondham in Norfolk (113 miles). Even after a week or two a number had travelled as far as 50 miles away.

Britain's annual Rat Week at the beginning of November is so dated to

catch the rats and mice on their return migration from the country where they have been living in the corn fields and hedges during summer. In November they move back to the barns, farmyards, and warehouses for the winter.

In winter when waters are frozen, otters will wander over considerable distances. Their tracks show that they have sometimes crossed the Lakeland mountains from one lake to another. The flying mammals—the bats—do not migrate like the birds, although the big fox bats of Calcutta and other parts of India, which unlike our British bats are fruit-eaters, often make long journeys from their sleeping quarters to the scenes of their depredations. They have a wing span of 4 ft., however, as compared with 14 in. of the *Noctule*.

UPSETTING NATURE'S BALANCE

The spread of civilisation—and especially the coming of the caravans, ships, and other communications of commerce—have so completely upset the balance of Nature that we now find many animals living in countries they never reached previously by any natural migration, and where Nature never intended them to dwell. This also applies to many plants and insects, and not a few birds. Our rats, for instance, are natives of the Orient and were accidentally transported by commerce to Britain in the 15th century and onwards. It is believed that the black, or ship, rat came first, and that the common brown, grey, or sewer rat came later. Nowadays, the brown rat is the common countryside and town rat, and the black rat is confined to docks and quays. The black rat is naturally a tree rat and often enters so-called "rat-proof" warehouses by the roof. On the other hand the brown rat is a ground rat, and thus finds the countryside more to its taste.

It is in the blood of a flea that lives on the black rat that the trypanosome or germ of the dreaded Bubonic plague is carried. The insanitary conditions that encouraged these rats to swarm in London and Europe in the Middle Ages were the cause of the terrible Black Death, so vividly described in Harrison Ainsworth's story *Old St. Paul's*. Recent censuses have shown that black rats are increasing in London and in some other areas but there is no cause for the story that has been set about that there is a new danger of "Black Death".

Nor is there any need to re-label the ship rat the "Plague Rat" or "Death Rat", as some writers have seen fit to do. Modern Port sanitary conditions and public Medical Authorities have progressed so far that any risk of Plague is well under control. Indeed, since the compulsory fumigation of ships, Merseyside, one of the greatest ports in the world, has seen a phenomenal decline in the number of black rats from an average of 58.83 per ship in 1923 to the low level of 1.67 per ship in 1938. Although a special investigation at the Liverpool School of Tropical Medicine showed that five species of flea occurred on rats in the port, and that the plague flea *Zenopsylla cheopsis* occurred freely, an examination of 3,173 rats by the Port Sanitary Authorities failed to find any sign of plague baccilus. Odd cases of plague found amongst Lascars on ships arriving in the port are immediately isolated.

If rats increase so abundantly in this country, why is it that they do not increase so much in their native lands? The reason is that in their natural haunts they have natural enemies that act as Nature's brake to check any undue increase of their numbers. When they were accidentally brought to this country their natural foes were not brought too, so that they increase almost unchecked.

Of course, not every foreign animal

or plant will colonise a new country—the majority do not find food, and for some the climate is not suitable. Many may find a new and more acceptable diet, as when mongooses were introduced into the West Indies to exterminate the rat menace—for rats are amongst their chief prey in Africa and India—they turned to the domestic poultry and the song-birds, with serious results.

There are other familiar mammals of the countryside that are not natives. The fallow-deer—the small, spotted deer often kept in parks, and living wild in the Wye Valley and in Epping forest—are natives of the Mediterranean introduced to this country by the Romans. The grey squirrels are descendants of a Carolina species introduced from America as pets during last century. Muskrats and coypu rats, or nutrias, have escaped from fur farms to breed freely in the wild.

Even the common rabbit is not native to Britain. None of its remains are found as fossils, and Caesar, who mentions hares, does not mention rabbits in this country. The earliest English record of the rabbit is in 1272 and it is believed to have been brought by William the Conqueror. Yet the English rabbit was introduced to Australia, where they have not only swarmed as incredible pests, but increased their size too. English foxes taken out to Australia have also grown much larger than their ancestors. Pigs, cats, sheep and horses that escaped from the early settlers have gone wild in New Zealand. The pigs, reverting to their ancestral

The Hippopotamus, a huge African animal that sometimes reaches a length of twelve feet and a weight of twelve tons. They are found largely in swamps or in marshy forest land and are entirely vegetarian. There is a smaller species—the pigmy hippopotamus.

wild boar type, have become pests. In Spain a herd of camels, called "feral" or escaped domestic forms, has bred in the wild for generations and become famous. Even in some of the Welsh and Scottish mountains there are fine herds of wild goats, originally domestic goats but now as wild as their relatives abroad.

The Beaver, largest of the rodents, is an amazing engineer. It builds extensive dams with trees which it fells with its sharp teeth. Its scaly tail, used almost as a fin, can be clearly seen.

Probably New Zealand has suffered more than any other country from the introduction of too many foreign animals. In addition to the Scottish red deer, the big Sambur deer was introduced to North Island from India in 1876, and the English fallow deer and the Canadian moose to the South Island in 1901. Ferrets, stoats and weasels that were introduced as pets escaped and added to the troubles of the farmers. The black-tailed wallaby was brought from Australia in 1870, and in the same year the hedgehog came from England. Other introductions have been the European hare, the house-mouse, the Australian phalanger, the Tasmanian sooty opossum, and many birds and plants.

All these instances offer a severe warning of the folly of upsetting Nature's "natural balance" between the animals. There have even been suggestions in the last year or two to brighten up life in one of the West Indian islands by introducing the gorilla from Africa or the orang from the East!

Excepting in those cases in which Man can domesticate a creature for his own use—as the crossing of the North American bison with the Hereford steer to produce the famous "catalos" for more beef—naturalists are generally strongly opposed to the introduction of animals into strange countries, except to be kept in captivity, and under control, in zoological gardens.

There are great zoological collections of this nature at London with its country extension at Whipsnade. There are other zoos at Antwerp; the Jardin des Plantes, Paris; Berlin; Bronx Park, New York; Calcutta; Rangoon; Taronga Park, Sydney; Moscow and elsewhere.

Canada has given the North American bison a great sanctuary at Wainwright Park, and Poland preserves a sanctuary for the few remaining European bison. The Belgian Congo has a sanctuary where the gorilla is protected and must not be killed except in self-protection.

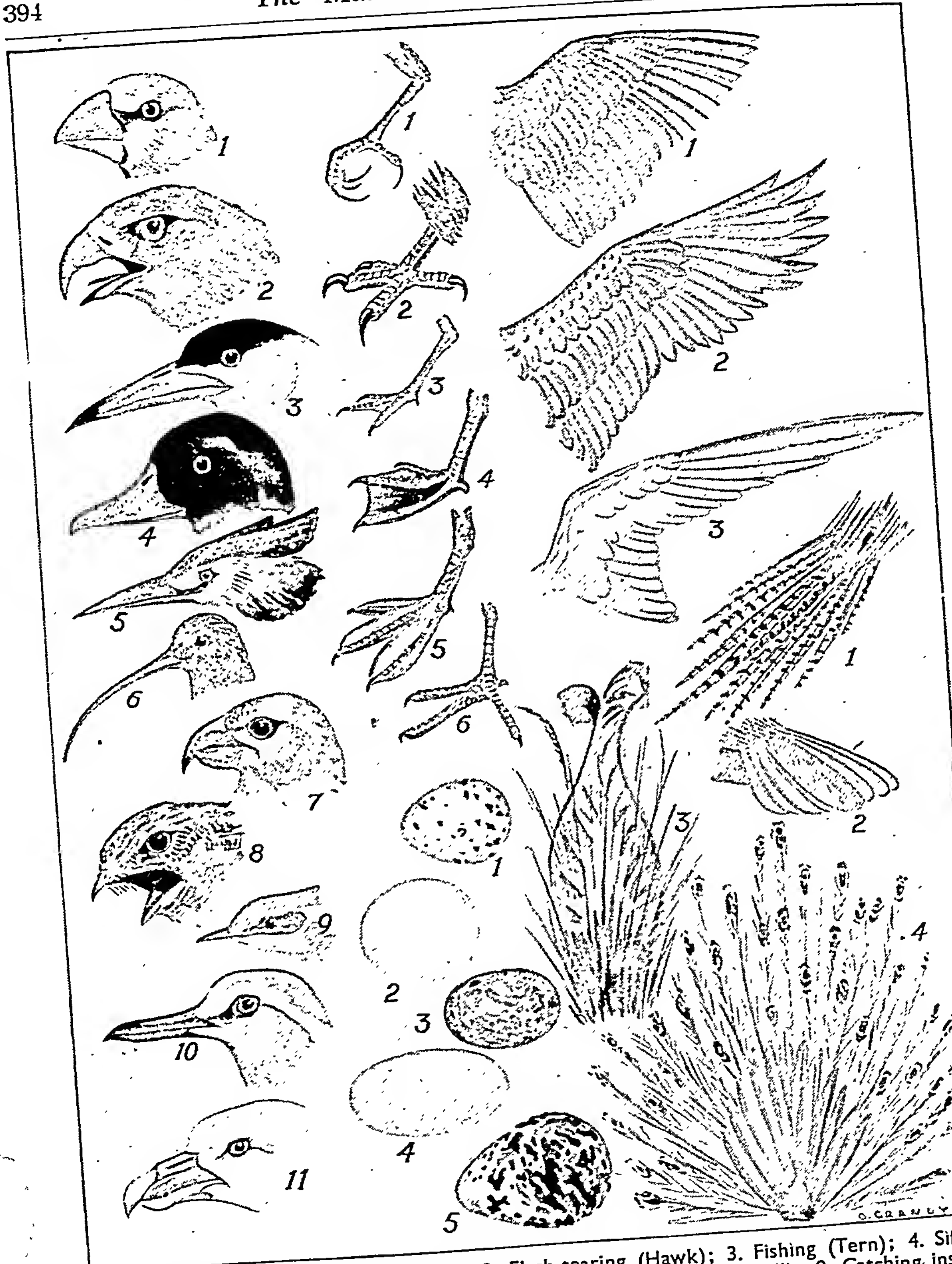


Fig. 1. *Beaks.* 1. Seed-crushing (Finch) ; 2. Flesh-tearing (Hawk); 3. Fishing (Tern); 4. Sif (Duck); 5. Fishing (Grebe); 6. Probing (Curlew); 7. Tapping (Crossbill); 8. Catching ins (Nightjar); 9. Insect-eating (Warbler); 10. Probing (Plover); 11. Tubed Beak (Fulmar Pet *Feet.* 1. Perching (Finch); 2. Gripping (Eagle); 3. Walking (Tern); 4. Webbed (Duck); 5. Lo (Grebe); 6. Wading (Moorhen). *Eggs.* 1. Thrush; 2. Owl; 3. Nightjar; 4. Grebe; 5. Plo *Wings.* 1. Short-distance (Sparrow); 2. Soaring (Eagle); 3. Long-distance (Tern); *Tails.* 1. Qu ascent (Pheasant); 2. Slow-ascent (Gull); 3 and 4. Courtship (Lyre bird and Peacock).

CHAPTER 17

BIRDS

EXACTLY as the mammals evolved from the reptiles—probably somewhere in Africa—so did the birds form another offshoot, changing their scales to feathers instead of hair, but retaining the scales of their ancestry on their legs. The first birds (*Archaeopteryx*, for instance) closely resembled the flying reptiles or Pterodactyls (Fig. 2) found as fossils, for they had teeth in their beaks and claws on their wings enabling them to scramble more easily over the trees. Although no modern birds possess such teeth there is a South American bird, the Hoatzin, that to-day shows these wing-claws as a nestling.

These early birds were really but gliders from tree to tree, as are the so-called flying squirrels to-day, holding their fore-limbs outstretched like a parachute. In due course they learned to increase their time in the air a little longer by flapping their limbs. In this way, and with the tail for steering, flight developed. Such active animals created a greater body heat, and a plumage of feathers maintained a jacket of air, and this being a bad conductor of heat kept the creatures warm.

In the same way that we can tell a mammal's habits from its appearance or structure, so we find a bird's structure is "moulded habit". The selection of wings and tails illustrated in Fig. 1

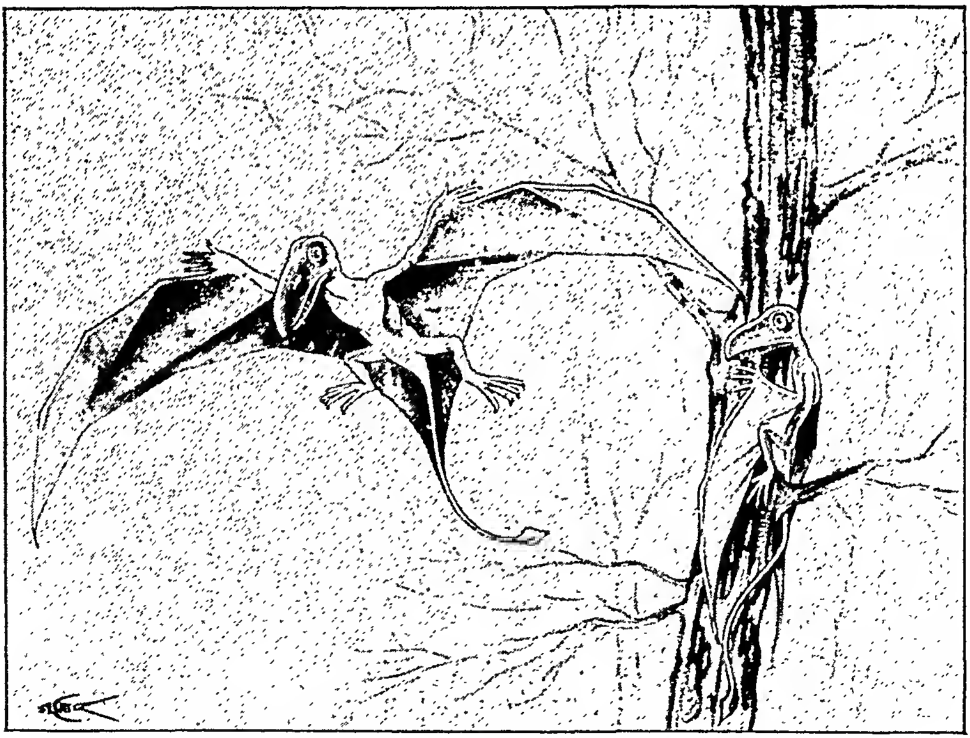


Fig. 2. An artist's impression of the Pterodactyls, the first flying creatures.

shows some of the more noteworthy types of these structures.

Birds with long narrow wings—such as the tern (3, Fig. 1) and also the albatross, gull, swift, and swallow—are long-distance fliers, usually migrating over many lands. Those with short round wings—the sparrow (1, Fig. 1) and game birds—are short-distance fliers. They seldom undertake great journeys excepting—as with the quail—when the winds help them.

TYPES OF BIRDS' TAILS

Birds with long narrow tails—for instance, the pheasants (1, Fig. 1) and sparrows—can rise suddenly into the air, but those with short tails—gulls (2, Fig. 1), plovers, and eagles—must sweep along the ground for some distance before obtaining sufficient lift to rise. Those with forked tails—kites, swallows, and terns—can double and turn swiftly in the air. Some tails, as that of the lyre bird (3, Fig. 1), are merely ornamental and are used in courtship. Other tails, such as that of the peacock (4, Fig. 1) have coverts, or covering feathers fitted over the true tail for ornamental purposes.

A bird's wings do not merely flap up and down in flight, for this would only cause the bird to turn a back sommersault. The wings move with a screw-like forwards - downwards, backwards - upwards movement, for a moving bird tends to fall forwards as well as downwards, and flight must counteract this. Incidentally, birds use their tails as brakes as well as for balance in flight.

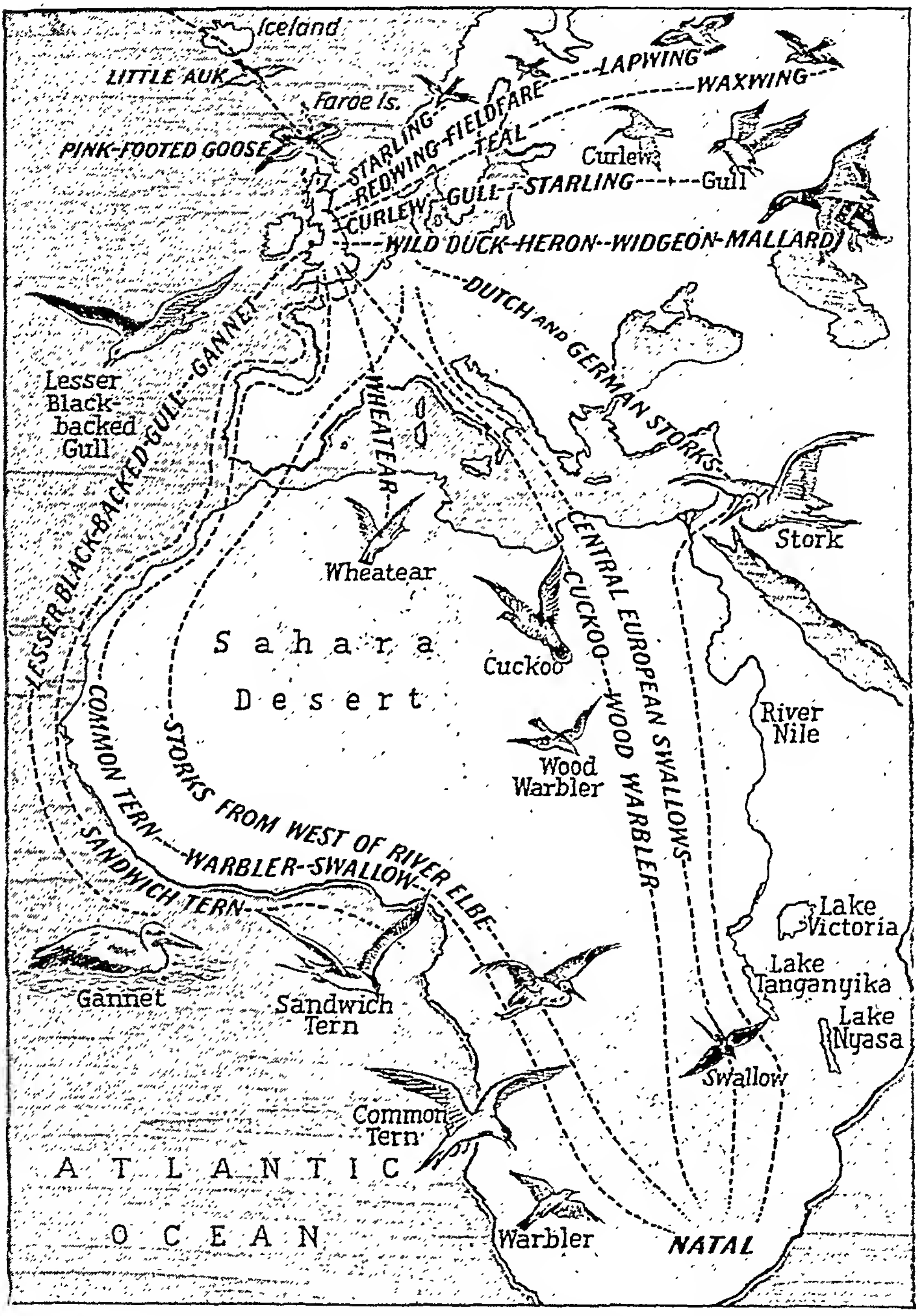
In the front of a bird's wing is a small bunch of feathers corresponding to the thumb, and easily seen when a pigeon banks round before settling. This is the bastard wing, corresponding to the slotted wing device on the Handley Page and other aeroplanes. By opening it, the bird can increase the wing-surface and thus slow down and glide before settling. Similarly, the ragged edges to the wings of crows and eagles—due to the wide spaces at the wing tips—allow the air to circulate round the narrower edges of the quills and thus help to control wing surface. Birds that soar or hover, of course, must face the wind to maintain lift. The wings of the Eagle (2, Fig. 1), have a pointed edge to give greater speed.

Some birds—such as the Tristan da Cunha rail, the African ostrich, the Australian emu, the Australian cassowary, and the Antarctic penguin—have lost the powers of flight, for they have no need for it. The penguin has developed its wings as flippers for swimming, and the ostrich uses its wings to aid running-speed. The New Zealand kea, which since the introduction of sheep has taken to killing them for their fat, is slowly losing its powers of flight, through lack of use.

THE MYSTERY OF MIGRATION

Bird flight has many interesting aspects other than its mechanical consideration. Migration is one of the marvels of science, for annually birds follow the coast-lines and the rivers' valleys to warmer winter haunts, returning in spring close to the place of their birth (Fig. 3). The lack of suitable food, as colder weather approaches, is the main cause of their departure after the end of the nesting season. This is hurried by the colder nights and the shorter duration of light. Their return in spring is hurried by sexual development and the increasing competition of their crowded winter haunts, where only the most competitive and adapted birds can stay to rear their broods.

By fixing numbered aluminium rings to the legs of wild birds—either as nestlings, or adults caught in large aviary-like "observatories" or ringing-



THE MIGRATION OF BIRDS

Fig. 3. Routes of European migratory birds, showing the enormous distances some of them cover. Although migrants fly over the sea, it is thought that they always follow ancient land bridges.

Fig. 4. The Short-Eared Owl. Notice how, unlike other birds', the owl's feathers are loose and ruffled. They lack the normal barbules.

stations, and then released—European and American naturalists have worked out most of the migration routes. One of the results obtained is the discovery of the fact that many birds as well as swallows return to their previous nesting haunts.

Swallows from Great Britain go to South Africa via western France, Spain, and West Africa. On the other hand, the German and central European swallows take a route over the Alps and travel via Italy and the Nile. Storks east of the Elbe take the easterly route via Asia Minor and the Nile. Those nesting west of the Elbe go via the south of France, Spain, Morocco, and the Great Lakes. Although all these swallows and storks winter in the Natal and South Africa region, they come home to their respective haunts without confusion (Fig. 3).

The larger Sandwich terns of Britain go only as far as West Africa for their usual winter haunts, but the common terns go to South Africa. This accounts for the fact that the Sandwich terns are usually first home in spring.

THE NESTING GROUNDS

In winter vast numbers of gulls and wild duck hatched in the Baltic countries spread over western Europe and Britain, where the climate is milder. British-born lapwings and thrushes, snipe and redshank, winter in milder Ireland or France and Spain. The kittiwake gull, a cliff-nester and much more oceanic than most gulls, which are more shore and marsh birds than true sea birds, migrates across the Atlantic in winter, for Northumberland birds have been found in Greenland and Labrador. Although English lapwings have been found in Newfoundland this was due to a gale that had blown them across when migrating to Ireland.

Most Arctic waders—the godwits, stints, and phalaropes—flock south in winter, travelling via western Europe to South Africa, or via Japan and China to India and Australia. The Arctic tern was found wintering near the Ross Sea, while the North American golden plover is a classic example of a 2,000-miles migration from the Hudson Bay to Central America.

Bird-observatories exist at Heligoland Island, in the North Sea; Rossitten, in the Baltic; Skokholm Island, off South Wales; Isle of May, near Edinburgh; and at many other places. Nearly 50,000 birds are ringed in Britain alone each year.

There is a vast mortality among migrating birds. The young birds usually start off before their parents, who are detained by the necessity of

rearing later broods. On misty nights lighthouses attract flocks, and they are often dashed to death against the lantern. On some English lighthouses special bird-perches have been erected on the balconies.

Swallows and martins taken from Germany and released at Croydon and other English centres, quickly homed to their German nests. Similar experiments with all kinds of birds show that during the nesting season most wild birds have as strong a homing sense as the well-known carrier pigeons. Most migrants fly at night because they must feed by day, and also because by doing so they escape their foes. The birds-of-prey seldom have to migrate for they do not rely so much on insect food. Birds obtain their extra energy from a sort of feverish excitement or "migration fever" that besets them at this season.

Birds' bodies, with their various arrangements, are very wonderful. The owl's feathers are not stiff and compact as quill feathers are in the case of most birds. They lack the little hooks or barbules that hold the web so stiff, and so they are loose and ruffled (Fig. 4). Because of this they do not strike the air with force and so ensure the silent flight required by the owl to catch its prey. Then again, in order that it may hear the movements of the rats and mice on which it preys, the owl has enormous ears, like great slits in its neck. The short-eared owl (Fig. 4) is really so named because of ear-like feathers that stand up on its head, but they have nothing to do with its ears. So that it may see better in the scant light of night, the owl's eyes are directed forwards instead of sideways, as in other birds, and they are surrounded by a disc of feathers that give the owl the characteristic spectacled appearance which is so familiar to the country-lover.

In contrast to these arrangements the snipe's feathers are so hard and stiff that in courtship it can hold the wings and tail so rigid as it swoops that the air zooms through them with remarkable loudness.

The gannet (seen in Fig. 5)—a big cliff-nesting relative of the cormorants (Fig. 6) and penguins—dives from a great height to catch its fish. Because of this habit it has no nostrils in its beak, and its breast is pitted with air-sacs to withstand the shock of the dive.

WHY BIRDS HAVE HOLLOW BONES

In order to lighten their bodies in flight, birds have hollow bones, and because such great muscles are necessary to work the wings, the breast-bones have an enormous keel to which these are attached.

The beaks and feet of birds (Fig. 1) like their wings and tails, tell much about

Fig. 5. The Gannet sitting on its nest. The Gannet is a sea bird; lives on fish and has no nostrils. Its habitat is the North Atlantic.

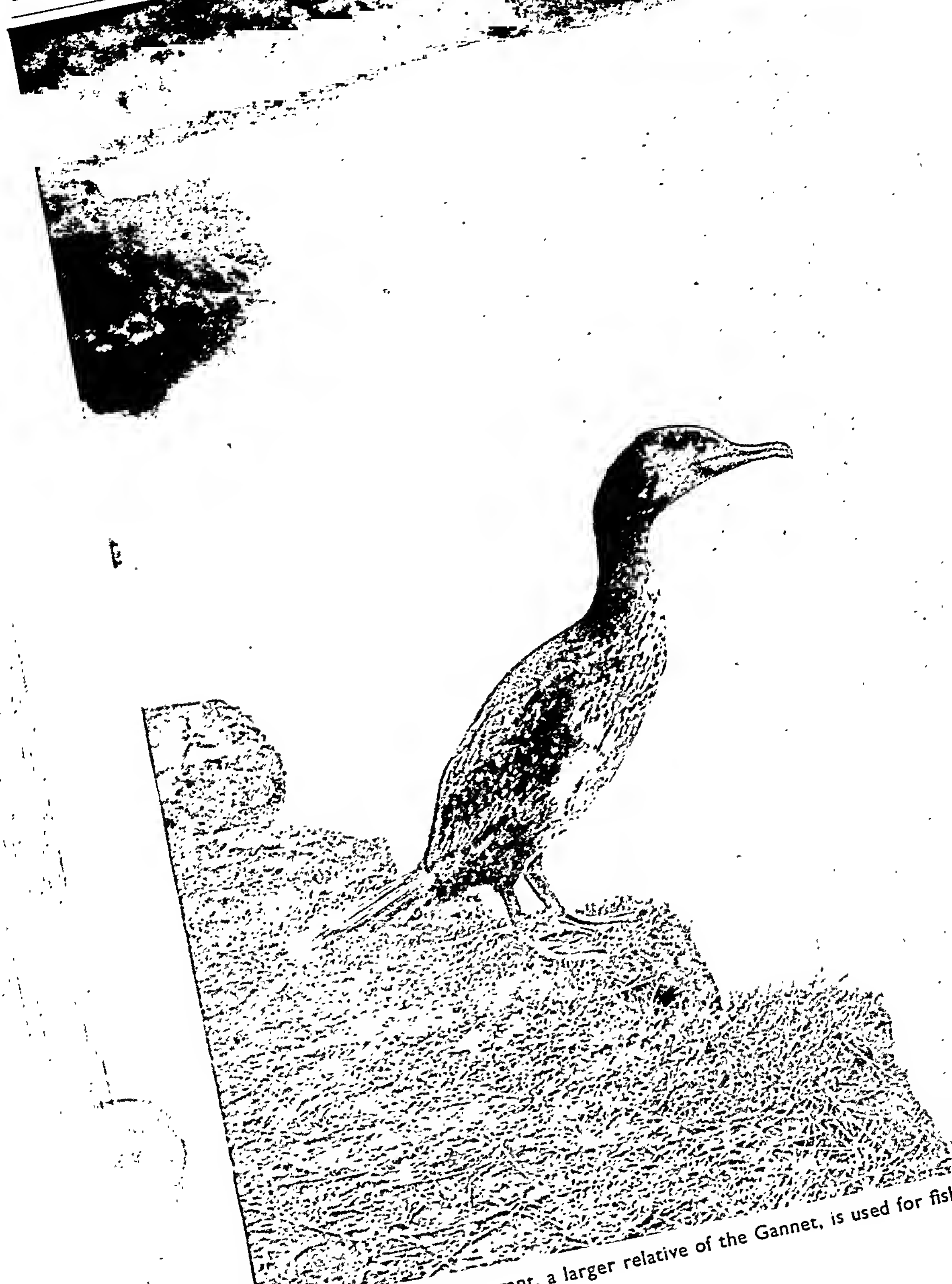


Fig. 6. The Cormorant, a larger relative of the Gannet, is used for fish

their habits. Birds with hook beaks—hawks (2, Fig. 1), owls, gulls and shrikes—tear flesh when feeding. Those with long narrow beaks—curlews (6, Fig. 1) snipes, woodcock and plover (10, Fig. 1)—probe soft mud. Those with broad shovel-shaped beaks, such as most ducks (4, Fig. 1), use them to sift the mud for food. They have ridges, or *lamellae*, around the edge to make the sieves. An exception among ducks are the fish-eating sawbills that have thick hooked beaks with serrated edges to catch their finny food.

The beaks of the tern, (3, Fig. 1) and of the grebe (5, Fig. 1) are long and pointed and are useful for securing food by fishing. The crossbill has a peculiar beak (7, Fig. 1) from which it gets its name. It is so shaped to enable it to open cones of conifers in order to extract the seeds. The fulmar petrel has a most curious tubed beak (11, Fig. 1).

Birds with very broad gapes—nightjars (8, Fig. 1), swifts and swallows—catch insects in flight. Those with sticky hairs at the gape, such as the fly-catchers, use them like a flypaper to catch more food. Hard, conical beaks, as those of the finches (1, Fig. 1), are to crush seeds, but thin soft beaks, such as those of the warblers (9, Fig. 1), are designed to feed on caterpillars and soft insects. Thus we know that the so-called hedge-sparrow, or dunnock, of the garden is no relative of the house and tree-sparrows, for with its soft beak and warbling song it is an insect-eating warbler, or accentor; the others with their hard, conical beaks are true sparrows, or finches (Fig. 7).

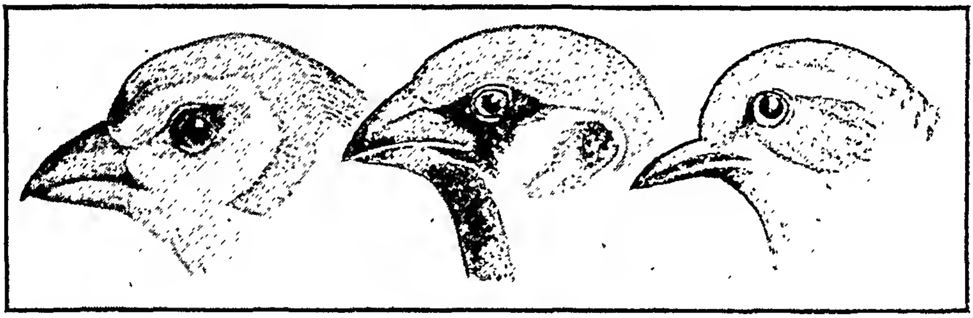


Fig. 7. The Hedge Sparrow (right) is not related to the House or Tree Sparrow (centre). The latter—the true Sparrow—is a member of the finch family like the Chaffinch (left).

Birds with very long toes, such as moorhens (6, Fig. 1) and jacanas, walk on floating lily leaves or very soft mud, and by distributing their weight as if on snow shoes avoid sinking. The ducks (4, Fig. 1) and other swimmers have webbed feet, or—as in the case of the grebes (5, Fig. 1) and phalaropes—they have lobes on each toe. Birds that dive deeply, like the grebes and auks, have their legs placed well to the rear. Perching birds have a well-developed hind toe (1, Fig. 1), and can go to sleep on a perch without falling off because the tendons of the leg—joined above and below the joint and passing over it—are tightened and held taut when the bird sits back, thus "locking" the joint.

The toes of the eagle (2, Fig. 1) are particularly adapted for carrying its prey by gripping it in its talons. Those of the tern (3, Fig. 1) allow it to walk about without discomfort.

The life of the bird simply bristles with mysteries to the enquiring mind.

After the nesting season, most birds moult. This takes place because they

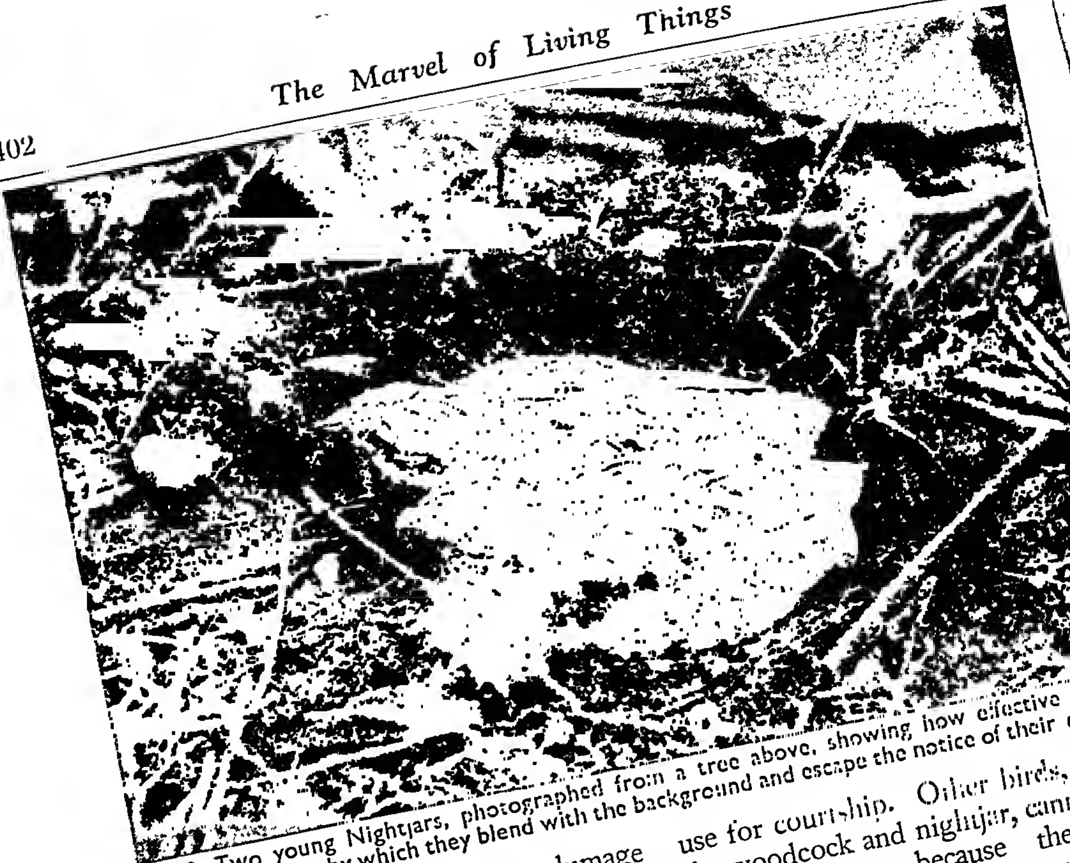


Fig. 8. Two young Nightjars, photographed from a tree above, showing how effective i
use of camouflage by which they blend with the background and escape the notice of their e

cannot carry such gorgeous plumage all year, for it wears down in the course of time and their bodies cannot afford to keep replacing such bright colours. Thus some birds—such as peacocks—often take on a duller plumage after the July or August moult, regaining the following spring the handsome plumage they

Warbler's nest, with two of
Cuckoo's egg.

use for courtship. Other birds,
the woodcock and nightjar, cann
bright colours because the
maintain a camouflage to esc
enemies (Fig. 8). These bir
courtship that consists of vario
and actions before the fem
nightjar claps its wings with
its back in flight; or, resting
before its mate, agitates its
kind of dance until finally
tail to show the white tips

COURTSHIP AND IT

The courtship of many
the making of a mock
wrens and ringed plove
present some of the b
to the mate—rooks an
pieces of stick; warble
great crested grebes,
phalaropes are a str
that the female court
after laying her egg
nesting duties, muc

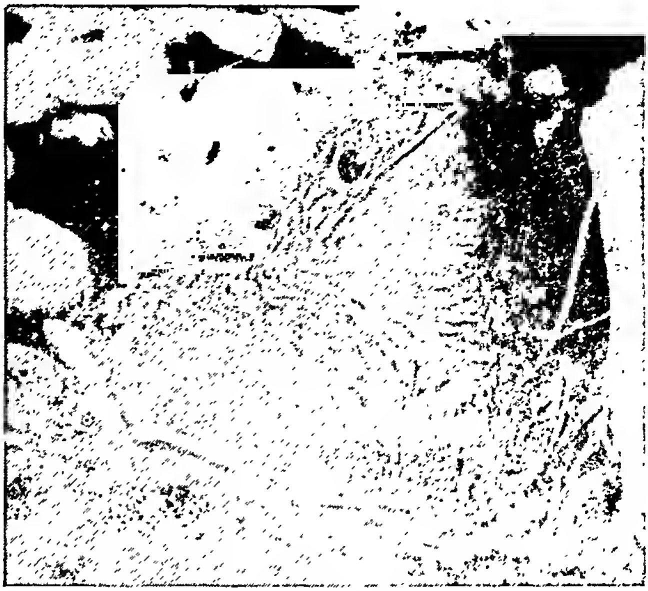


Fig. 10. A young Cuckoo in the nest of a Hedge Sparrow. This bird is very nearly full grown and ready for flight.

emu leaves her eggs for her mate to hatch and rear. These are exceptions, however, as in most cases both birds help to build the nest and incubate the eggs, with the mother bird doing the bulk of the work. With some, such as the wild duck, the male has little to do with his wife after nesting starts, while many male birds simply bring food to the female and leave her to feed the young.

The hornbill of Africa and India nests in a hole in a tree, but so soon as the hen bird begins to sit, the male plasters up the entrance. She is kept a prisoner, in some cases for two or three months, while he feeds her through a small slit in the mud. In this way he makes certain that she does her duty!

The starling, the kestrel, and the crow often usurp the nests of other birds instead of making their own, whilst—as everyone knows—the common cuckoo lays its eggs in the nests of pipits, wagtails, and warblers (Fig. 9). For a long time it was thought the cuckoo laid its egg on the ground, then carried it in its beak to the nest, but this is not so for the bird has been clearly observed—and actually filmed—laying direct in the nest like any ordinary bird. A cuckoo will lay about half-a-dozen eggs in a year, usually within a range of from half-a-mile to two miles. It is interesting to find that a cuckoo hatched from, say, a hedge-sparrow's nest will prefer to lay its eggs in hedge-sparrow nests (Fig. 10).

The cuckoo has many relatives in India and elsewhere that make their own nests and hatch out their own eggs. The reason for the common cuckoo's parasitic habits is probably that it migrates from Britain so early, owing to a shortage of its natural insect food, that it would not have time to rear its own young. They stay longer in the country and can vary their diet.

HOW BIRDS LAY

Birds do not lay their eggs all at once, but usually an egg a day—or, as with the birds of prey, an egg every other day—until the clutch is completed. The owls and some others commence to sit as soon as the first egg is laid, and thus we may find youngsters of all ages and sizes in the nest. Most birds, however, do not sit until the clutch is complete.

Some birds, like the auks of the sea-cliffs, have but one egg in the clutch. Pigeons have two; plovers three; gulls four; most finches (Fig. 11), thrushes and warblers four or five; the titmice seven or eight. Wild duck, moorhens,

Fig. 12. A Nightjar's nest is one of the most primitive of nests, a mere scrape in the ground.

and game birds may have even a dozen. The ostrich often has over a dozen eggs in its nest.

The most primitive nests are but scrapes in the ground to hold the eggs, as with plovers and nightjars (Fig. 12). The nests of larks and pipits are a little more developed, being hollows in the ground lined with a bed of grass (Fig. 13). From this type we proceed to the more primitive adaptation of the nest to the tree, where it is free from the unwelcome attention of ground vermin. Such nests vary from the frail platforms of sticks of the doves and pigeons to the more substantial deep cup-nests—held together with mud and fibre—of the thrushes (Fig. 14), and the artistic weavings of moss and spiders' web that are the domed, bag-like nests of long-tailed tits.

Some birds line their nests with feathers (Fig. 15) making a soft warm bed for the young. The eider duck plucks feathers from its breast for this purpose, and we use these feathers in the "eider-downs" of our bedrooms.

In India, the lovely little tailor bird collects threads and sews together leaves to make its nest. We have nothing like this in this country but some birds come rather near it by preparing a "roof over their heads" to an open nest (Fig. 16).

In Africa the weaver finches construct great communal nests in the trees. In

Fig. 11. A Chaffinch's nest. Note how beautifully the nest is built on the branch.

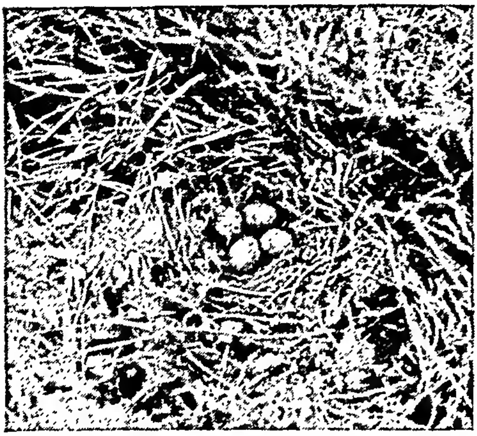


Fig. 13. (Left) a Skylark's nest. (Right) a Redshank's nest. These nests are an advance on the type shown in Fig. 12, being lined with grass, but they are still on the ground.

Malaya the edible palm swift makes a glassy nest of hardened saliva from its mouth, and this nest the Chinese favour for costly soups. Woodpeckers chisel their way into rotten wood to make a nest hole. Nut-hatches take a natural hole and plaster the entrance with mud to suit their size. Parrots excavate holes in tree trunks.

Tomtits, robins and wag-tails will nest in any convenient hole, natural or unnatural, so that we often see the first nesting down the spout of an old well and the last in an old bucket or discarded teapot in the garden shed (Fig. 17). Swans and grebes make great floating nests in the reed beds of lakes, anchored to the reeds (Figs. 18 and 19). The reed-warbler suspends its nest from three or four stalks, making it very deep in order to prevent the eggs or young being tipped out when the reeds are made to sway by the wind.

We have seen that the colours of birds' plumage are for two purposes, either to hide or camouflage their bodies from predatory foes, themselves usually of duller plumage, or—in the gaudy plumages—to attract the female.

Fig. 14. The nest and eggs of the Song Thrush. This nest is cup-shaped, and lined with cow-dung, mud and decayed wood. The bird shapes and smoothes this mixture with its breast.

The colours of birds' eggs also have a purpose. The eggs of birds that lay in holes—owls, woodpeckers and king-fishers—are white, for obviously colour would be wasted in such surroundings. A few hole-nesting birds, such as the starlings, have pale-coloured eggs, how-ever, and it is believed that these birds have taken to their present nesting places only in comparatively recent times, and that the pale eggs are gradually losing their colour. The eggs of wood-pigeons and turtle-doves are coloured white so as to harmonise with the sky when seen from below, for the eggs rest only on thin platforms of sticks that make the nests of these birds.

The bright blue eggs of thrushes and

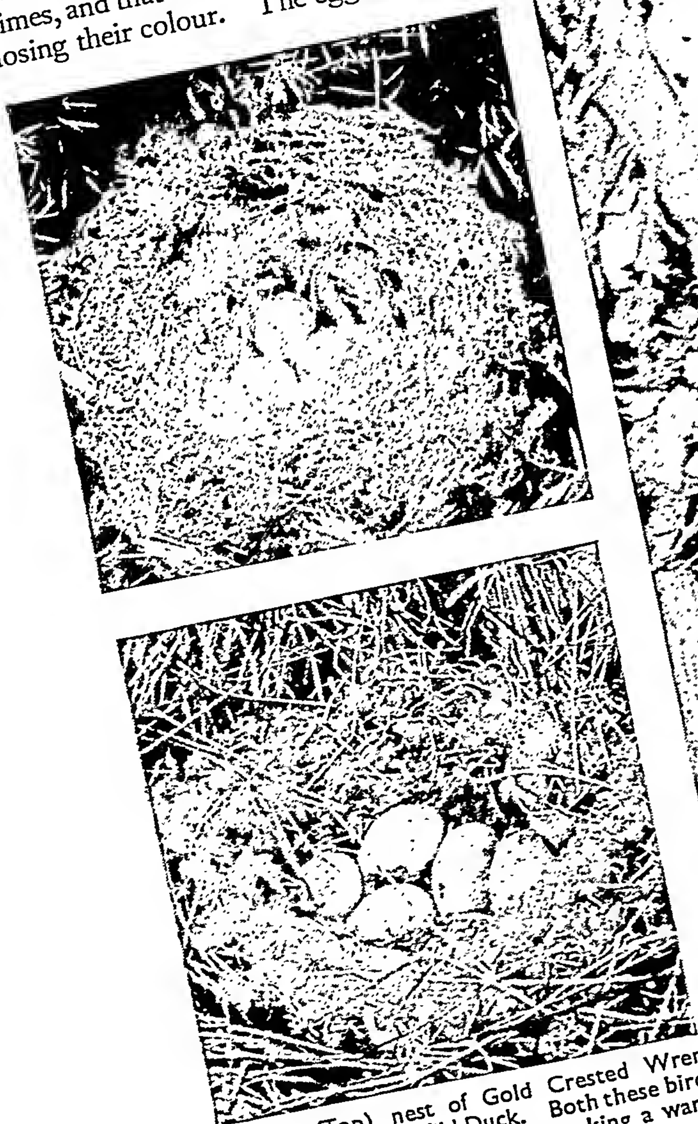


Fig. 15. (Top) nest of Gold Crested Wren. (Bottom) nest of Wild Duck. Both these birds line their nests with feathers, making a warm bed for their eggs.

Fig. 16. Wood-wren's nest, a beautifully made roofed nest, comfortable and weatherproof.

Fig. 18. The nest and eggs of the Little Grebe, built among some lakeside reeds and floating on the water.

other birds are more or less hidden from enemies by the deep walls of their cup-shaped nests. It is supposed that their bright colour acts as a stimulant to the bird to incubate them, just as the bright orange lining to the mouth of a nestling thrush stimulates its parents to feed it every time they see that gaping mouth calling for food.

Although we refer to "egg-shaped", as in the egg of the hen, there is really no general egg-shape in bird life. The so-called egg-shape, or ovoid, as represented by the egg of the thrush (1, Fig. 1), is typical of the game birds and ducks, for the domestic fowl is a variety of the jungle fowl, one of the game birds. The shape of an egg often denotes the kind of bird that laid it as much as does its colour. The eggs of snipe and plovers, for instance, are easily recognised by being pear-shaped (5, Fig. 1). Those of the grebes and swallows are bi-conical, having each end pointed (4, Fig. 1 and Fig. 19). Those of the nightjars are oval with each end rounded (3, Fig. 1). Those of the owls, sparrowhawks and king-fishers are noticeably round or spherical (2, Fig. 1).

Fig. 17. A pied Wagtail's nest, constructed securely in an old tin can.

The size of an egg has nothing to do with the size of the bird, for although the egg of a partridge is about the same as that of a snipe, the latter is much the smaller bird. The cuckoo lays a relatively small egg for its size, for it mimics the eggs of meadow-pipits, wagtails, and other small birds. On the other hand, the egg of the guillemot of the cliffs is very large in comparison with the size of the bird.

Nor are all egg-shells alike, although

most birds lay smooth eggs, as in the case of the thrushes and the moorhens. Some eggs, such as those of the woodpeckers, are very much more glossy—those of the partridge and tinamou appear almost to be made of porcelain. The eggs of the ducks are greasy, for they have to withstand the wet bodies of birds coming from the water; those of the grebes and cormorants have a chalky deposit. The eggs of the bunting are usually known by their markings of wavy lines giving them an appearance that looks as though someone had tried to write on them.

SOME POPULAR ILLUSIONS

Popular illusions about birds extend further than the use of the words "egg-shape" that would suggest that all eggs are alike. For instance, there is the popular idea that owls hoot. Actually only very few owls hoot, and these include the common brown or tawny wood owl. The white barn owl screeches; the little owl has a wailing cry; the long-eared owl barks, and the short-eared owl snorts! Another mistaken idea is that all ducks "quack", because the common farmyard duck is a domesticated form of the common wild duck or mallard that quacks. Actually most wild ducks call with whistles, as the widgeon, or grunt as the tufted-duck.

It was from their primitive calls that birds evolved their wonderful songs. These are not sung merely for our enjoyment, for there is a definite reason behind bird-song. In late winter and spring it often is a war cry by the cock bird, when he has selected a nesting site. With "squatter's rights", or a strong sense of territorial possession, he announces his offer to any passing female bird, or alternatively warns any rival male that "trespassers will be prosecuted". A bird will sing day after day from approximately the same perch, and in all probability if a search be made its nest will be found close by. Female birds, and those birds that live in rookeries and heronries and similar colonies, rarely sing.

As the nesting-season duties make further demands on the male's time, however, the courtship song ceases. Nightingales, for instance, become increasingly nocturnal singers as June approaches. The mistle-thrush drops out of song very early, actually about May, for it is an early nester. Again, at the end of the nesting season in July or August, when birds moult their nesting plumes, there is a marked silence in the countryside save for a few buntings and starlings. In autumn, however, some larks, thrushes, robins, chiffchaffs and willow-warblers, commence song again but in a less vehement manner, for now they are singing from individual happiness. At times the thrushes may sing a quiet subdued song with closed beak as though singing to themselves down in their throats. Normally, a bird's throat pulsates in song, because its voice-box, or syrinx, is very low down the windpipe where it branches off to the lungs. With the mammals, of course, the voice box is almost at the top of the wind-pipe.

THE SPRING—DAWN CHORUS

One of the most brilliant performances of bird song is the dawn chorus in spring. No doubt it is an expression of exhilaration welcoming the returning light after the fearsome dark of night. The reflection of the rising Sun coming into the sky about an hour before sunrise, is first heralded by the earliest risers—the larks, robins, thrushes, rooks, and wrens. Later, the blackbirds and warblers come in, and then the finches, starlings, and titmice. Before sunrise the peak of the volume of music is passed and the chorus begins to ebb.

In the evening there is a chorus of quieter music at the end of day, and it is curious that the earliest risers in the morning—the lark, robin, and song thrush—are the last to sing before retiring at night. Those last to rise in the morning—the house-sparrow, starling, great-tit, and blue tit—are amongst the first to retire from the evening song—a curious fact.

BIRD SONGS AT NIGHT

Of course, many more birds than the nightingale sing at night, especially on a warm summer night, which from mid-May through June is really a prolonged twilight. Especially is this so with the sedge and reed-warblers, the cause of many a false "nightingale" report. The cuckoos, nightjars, and grasshopper-warblers; the lapwings, moorhens and stone-curlews, call frequently at night. On the seashore the feeding and roosting of the gulls and waders is controlled by the movements of the tide that covers and uncovers their food, and not by the coming of light and dark. Here is a medley of cries that vary from the "scree-arrs" of fishing terns to the bickerings of waders and the screams of gulls. These are heard even in the middle of the night if the tide is on the ebb.

This brings us to the question of birds' food. We have already seen how the shape of a birds' beak has generally been evolved to enable it obtain its particular kind of food. There are also other features of birds' bodies that are designed to this end. The long and scaly legs of the secretary bird keep it safe from the bites of the snakes it catches in the long grasses of the African plains. The long legs of the heron enable it to wade out into mid-stream to catch the fish on which it lives (Fig. 20). The curiously crooked beak of the flamingo, which made such a useful croquet stick for Alice in Wonderland, is devised so that the long-necked bird can hold its head down and swish its beak from side to side in the shallow water as it sifts for food. Birds of prey, such as hawks and falcons, do not catch their food with their hooked beaks. They strike down their prey with their talons, carry it in their talons, and tear the flesh with the hooked beak.

The song thrush has a curious habit of breaking snail shells on large stones, and these stones—the "thrush's anvils", as they are called—are littered around with broken shells. It is curious that the closely-related blackbird has never discovered this trick. On the seashore we can watch the sea gulls lifting cockles and mussels in their beaks and dropping them from a height on to the hard rocks to break the shells. Sometimes they drop them on the soft sands when they miss their aim.

The stories about the ostrich's wonderful digestion are not due to the fact that the bird will eat anything and subsist upon nails, bootlaces, and all the other odds and ends that have been found in these birds. It is because birds have no teeth and to crush and break up their food they have a hard gizzard, situated above the stomach. It is filled with grit or small stones that masticate the food as it passes through on its way to the stomach. The ostrich, being the largest of our birds, naturally requires larger grit than the others. When it cannot find enough pebbles it collects all sorts of curious objects, but although it swallows them it is not eating them.

BIRDS OF PREY

If we look at the head or neck of a condor, vulture, or cormorant, we notice that much of the skin is quite bare (Fig. 21). These birds feed on carrion—dead birds and beasts in the case of the vulture and condor, and

Fig. 20. A Heron fishing. The Heron is a beautiful water bird found throughout the world.

1. The head of the Pondicherry Vulture. Notice that the of the head is almost free of plumage. This is Nature's way suring that the bird is not fouled by the carrion it eats.

the plant seeds within. The mistle-thrush is most partial to the rowan fruits on the mountain ash, but most thrushes take hips and haws. The blackbird is fond of holly berries. The favourite food of the starling is the soft purplish berry of the elder. Alder tree fruits have a strange attraction for siskins and red-polls and they probably search them for insect life.

Bullfinches have an inveterate habit of biting buds, but as in the case of the sparrows, they disdain the bitter buds of the black currant

fish in the case of the cormorant. ı food would soon foul any plumage ınd the neck, hence its absence.

'he condor has the finest eyesight in world and can detect a carcass when bird is so far off that it appears but a ck flying in the sky. Most birds long-sighted but, except in the owls, :ir eyes are not in the same place as rs—they see a different field of view ı each side of the head. Thus, the rush hopping across the lawn in :arch of worms must cock his head to ne side every now and then to see if ny tips of worms are protruding from heir burrows—he is certainly not istening for worms moving through :he soil as many people assume. If we throw some strange food to a hen in the farmyard it will "eye" it with cocked head in a similar manner.

Have you ever wondered why most berries are red? This is because red is the favourite colour of the thrush tribe of birds and they feed extensively on these berries, thus helping to distribute

shrubs, although readily taking the buds from red currants. Crossbills, lovely crimson finches from the fir woods of Northern Europe, have the beak curiously crossed at the tip, so resembling pincers (7, Fig. 1). This enables them to prise open the scales of the pine cones and feed on the oily seeds within. The hawfinch—the gaudy, white-rumped finch of the big woods—has an enormously large conical beak. Although it collects berries, it feeds on the hard kernel within, rolling it around the edge of its beak as a canary will roll its seed, until finally it cracks it in two.

The humming birds of the New World and the sun-birds of the Old World, have long slender beaks and long tongues to reach the nectar in the flowers on which they feed. Whereas the humming birds hover before the flower to feed, the sun-birds perch nearby.

You may have wondered why the swan and the goose have such long

necks as compared with the ducks, although all live in water. Our wild ducks are divided into three groups according to their food. These are the surface-feeders, such as the common mallard that live largely on vegetation; the diving duck, such as the pochard, that dive for food below the surface; and the saw-bill, or fish-eating duck, such as the goosanders that also dive. The swans and geese cannot dive, however, and so they have long necks to grub about the bottom of the water while still swimming on the surface.

WHY DUCKS HAVE OILY PLUMAGE

Perhaps, too, you have wondered why water runs off a duck's back so easily? These aquatic birds have a very compact oily plumage, and if we watch a bird preening its feathers we notice that it frequently touches the base of its tail. This is because an oil gland there secretes a little oil that the bird uses to keep its plumage sleek. In the duck tribe the oil gland is very well developed. It is interesting to notice that when preening its plumage the bird can twist its head completely round to reach its back—this is something that humans and mammals cannot do. A bird's skull is fastened to its backbone by only one knob, or condyle, whereas the skulls of Man and the other mammals are fastened by two knobs or condyles, and it is for this reason that they cannot move so freely.

There are about 70,000 different birds in the world, about 500 different species and varieties having been recorded from the British Isles alone. A careful watcher in any parish should be able to see between 100 and 200 different species of birds. Now, how are we to remember one from the other and identify the various birds we see in the country-side? This is where the scientific classification of birds helps, for if we know only a few distinguishing features about each of the big bird groups, we can quickly place any strange bird into its respective group and thus identify it easily.

Birds are grouped mainly according to their structure, although superficially some birds may not seem related. Just as among mammals many people may think the hedgehog and the porcupine are cousins until they examine their teeth, so is it usual to confuse the house-sparrow and the garden hedge-sparrow as cousins until we examine their beaks. As we have already explained, the former has a hard, seed-crushing beak typical of the finches, whilst the latter has the soft, slender, insect-eating beak of the insectivorous warblers (Fig. 6).

Carrying further our examination in this direction, we find that the solan goose, or gannet, is not a true goose, but is a relative of the cormorants and pelicans. That the willow-wren and golden crested wren are true warblers and not wrens at all, except in popular rural nicknames. Reading the scriptures we notice that the word denoting "eagle" evidently has been mis-translated, for because of its carrion-feeding habits and its bare neck or head, the eagle of the Bible is obviously a vulture.

"PNEUMATICITY" OF BONES

We have already mentioned that birds have hollow bones. It is curious that this hollowness, or "pneumaticity", is not always in proportion to the flying powers of the bird. Thus the hornbills of the East, which are poor and heavy fliers, have all their bones—including even their back-bones—so hollow that they are reduced to mere shells. On the other hand, in their not very distant cousin, the rapidly flying swift, the pneumaticity of the bones is reduced to a minimum. It is necessary, of course, that the strength of the bones should be increased according to the speed of the

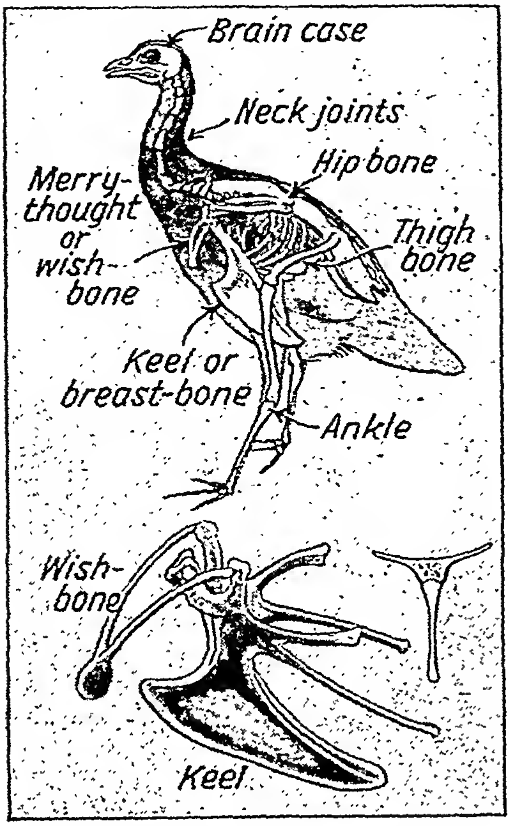


Fig. 22. (Top) Positions of fowl's principal bones. (Bottom, left.) The keel, showing how the wish-bone is attached. (Bottom, right.) End-on view of keel, showing how thin it is.

bird in order that they will stand up to the great pressure of air as the bird speeds through the air.

While dealing with bones, we may mention the "merry-thought" or "wishing-bone" of the chicken and the Christmas turkey. This bone—the furcula—stands in front of the breast-bone with its enormous keel (Fig. 22). Actually it is the collar bones, or clavicles, well developed and united together to form the familiar V or U-shaped bone so popular with the youngsters.

Modern ornithologists commence their classification of the bird world with the perching birds. Birds of this class have well-developed hind toes that enable them to perch, and they are headed by the crow tribe, the most intelligent of all birds and far more intelligent than the "talking" parrots. The crow family includes such dissimilar birds as the black-plumaged carrion-crow, raven, rook and jackdaw, the black and white magpie, the gaudy jay (Fig. 23) and the bird-of-paradise. Members of this family are all recognised by their typical corvine beak, which is fairly thick and deep although not hooked, and also by their walking gait. Another feature is that they have ten wing feathers and twelve tail feathers.

THE NEW ZEALAND HUIA BIRD

A remarkable member of the crow tribe is the Huia bird of New Zealand, the tail feathers of which are worn as a badge of mourning by the Maoris. This bird is curious in that the cock and hen bird have entirely different beaks. The bill of the male huia is rather short and straight, but that of the female is long, curved, and slender. So great is this difference that early naturalists thought they were two entirely different birds. A similar mistake was made by the early English naturalists when they separated the male and female hen harriers because of their different plumages, the one grey—the old harrier—and the other brown, the "ringtail."

From what we have learned of the origin of structure in birds and beasts we can readily assume that the huia birds have these differently shaped beaks because they put them to very different uses. Actually, the male bird attacks the decayed timber of trees sometimes to enlarge a hole for its nest, at others to feed on beetle grubs that infest the rotten trees. On the other hand, the female probes the other hollow parts, the harder outer wood of which prevents her chiselling through. The huia is a black bird of the forest shade, and as in the case of so many of New Zealand's native birds, it has become very rare

Fig. 23. The mischievous Jay is a member of the Magpie and Crow family. Jays, like crows, are noisy birds, often brightly coloured, with a peculiar habit of destroying other birds' eggs.

since humans developed the country.

The birds of paradise, which are among the most brilliant birds of the world, have gaudy plumes as an asset in their courtship. These are what are known as "secondary sexual characteristics", as are the beards in human males, cocks' combs and wattles, stags' antlers, etc. When kept in captivity, as at the Zoo, it is found that these birds must be isolated after mating, for if partnered and left together the cock is almost invariably henpecked to death! As with the peacocks and pheasants, these gaudy plumages are usually confined to the male birds, the females being brown and of a somewhat dowdy appearance.

BIRDS OF PARADISE

The great bird of paradise, which is almost as large as a magpie without its tail but more slender, is of a very rich shining brown colour with an emerald green throat and yellow head. Its eyes are yellow and its legs and feet pink. Growing from under the wing on each side of the body are tufts of gorgeous orange-gold feathers. They hang over like golden palms and drape down over the sides, some being from 18 in. to 24 in. in length. Its habit of suddenly shooting these golden-yellow feathers up into the air has a very sensational effect. It inhabits the East Indies and feeds on fruit and insects. As in the case of the blackcock of the Scottish pine woods, the males gather together in parties of twenty or so, to perform curious courtship dances and mock duels for the entertainment of the dull-brown hen birds.

Closely related to the birds of paradise are the amazing bower-birds of Australia. Their name arises from the fact that the cocks make a bower or archway of twigs, feathers, etc. Through these arches, which are decorated with shells, bones, and any bright objects that catch their eye, they perform their curious runs. These bowers have nothing whatever to do with nesting, and seem to be erected solely for the amusement of the birds.

The weaver birds are a group or family deriving their name from the extraordinary communal nests they erect in the trees in Africa, South East Asia, and Australia. Although they closely resemble our finches, they differ in having ten wing quills, whereas the true finches—the sparrows, bull-finches, etc.—have only nine wing feathers and twelve tail-feathers. The weaver birds are all small, hard-billed, seed-eating birds, although they rear their youngsters on soft food. Even the garden sparrows can be seen feeding their youngsters on greenflies, or aphides, collected from the foliage.

The so-called Java sparrow, one of the commonest of European cage-birds and a familiar house-nester of the East, is not a true sparrow but is one of the weaver birds. It is also called the rice bird and the paddy bird, because it infests the rice or paddy fields of the East. It is a handsome lavender-grey bird with a black and white head and pink beak.

Another lovely little group of finch-like birds, the tanagers of America, have very similar conical beaks except for the little notch at the base.

THE FINCH'S BILL

In the true finches we see the seed-crushing bill developed to an enormous extent in the hawfinch of the woods of Europe and Asia, which has to crack the hard kernels of the berries, and in its relative the grosbeak of America. The latter is a relative of the red-crested cardinal of cage-bird enthusiasts, the so-called "Virginian nightingale".

Although the finches are more or less resident birds as compared with the very migratory warblers, some members

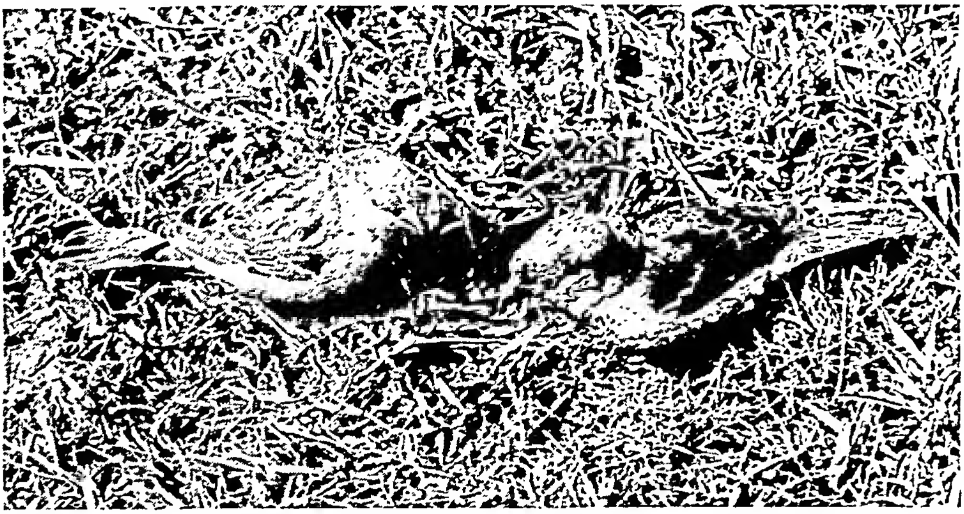


Fig. 24. The khaki-and-brown plumage of the Sparrow forms a camouflage against most backgrounds. This is one reason why Sparrows are so numerous, for it contributes largely to their safety.

of their group undertake long journeys. Every winter the bramblings—such as the black, white and chestnut finches—of the beech woods, identified by their white rumps, migrate in flocks from North Europe to Britain and south-western Europe. High up on the slopes of Everest the little snow-finches have been amongst the last birds to be noticed by the various explorers, for on the plateaux they share the burrows inhabited by the mouse-hares and utter a sweet song at moonlight. Other birds typical to Everest scenery are the yellow-billed alpine chough, the rock pigeon, the brown and red-breasted accentors—close relatives of the English hedge-sparrow—and the rose-finches. As high as 16,000 ft. the lämmergeier, or bearded vulture, has been seen flying round in search of its carrion prey.

The commonest of all the finches—indeed, of all birds—is the house-sparrow. It has conquered the world with Man's civilisation, and is rarely found far from the habitations of man. Introduced to North America from Liverpool in Victorian times, it soon spread to reach saturation point over the United States and Canada, just as the starling, which was introduced later, is spreading to-day. In the Eastern countries, however, the brown-headed tree-sparrow is holding its own. It is believed that in the past the house-sparrow was not a very abundant bird and that before the world became so densely populated the tree-sparrow was the more numerous of the two, the house-sparrow gradually ousting it from many of its one-time strongholds.

ADAPTABILITY OF THE SPARROW

One of the reasons for the great success of the sparrow is its adaptability. Its khaki-and-brown plumage is very good as a general camouflage (Fig. 24) and it can either build a nest in a hole or as a domed bundle of straws in the branches of a tree. It will nest almost every month from February to October and can bathe in both water and dust. Although it could not well withstand the hard winters when first introduced to North America, it has overcome even that difficulty. It has been computed that if all the offspring of a single pair of house-sparrows survived for

Fig. 25. The Australian Kookaburra or Laughing Jackass, is a type of kingfisher which lives on small vermin. Birds of prey find kingfishers' flesh distasteful; and this helps to protect them.

ten years the progeny of the original pair would number 275,716,983,698!

Another finch that is steadily increasing its range is the little serin. It has spread up the Rhône valley to the North of France and in future years may well colonise southern England.

The common canary is, of course, a member of the great finch family. Whereas in the wild its plumage is an ashy brown and yellow, it has been bred almost pure white by cage-bird enthusiasts, who have produced such freak forms as the hump-backed Scotch variety, the Crested Norwich, and the Old Green Liverpool.

It is usual in finches for the sexes to differ in colour and for the cock to be more handsome than the hen, as with the chaffinch and the bullfinch. There are a few exceptions, however, as in the goldfinch, where the sexes are alike.

The buntings, an interesting little branch of the finches, include the common yellow-hammer of our cornfields. At harvest time they are the dominant songbirds of the countryside with their "little bit of bread and *no* cheese". Buntings differ from true finches in that their bills do not touch along the whole length of their margins —in other words there is a slight space between the two halves of the beak. In their case the sexes are much more alike than with the true finches.

Members of the lark family—all active, ground-feeding birds—are easily recognised. As in the case of their allies the pipits, they are characterised by the enormous development of the long hind or first toe that seems like a little spur at the rear of the foot. One group, the short-toed larks of Spain and the Mediterranean, winters in Upper India and its members are without this usual feature. The wagtails and pipits are

much more active birds and usually frequent the vicinity of water.

The tree-creepers, forming the next group, are small, tree-trunk birds. Their slightly long and slender, curved beaks are used for collecting insects and spiders from the bark. Their long curved claws give them a strong grip of the bark. These little birds roost at night in the fissures of the bark on the leeward side of the trees.

THE BEAUTIFUL SUN-BIRDS

The sun-birds, the gorgeously coloured little birds of the Old World, seem to take the place of the famous humming birds of the New World in their activity and nectar-loving habits. There is a difference, however, in that the humming birds hover on the wing when sipping at the flowers whereas the sun-birds never seem to hover before the flowers.

The wrens are known by their smallness, their comparatively long claws, and curiously upturned little tails. Next to them come the dippers—aquatic birds of our swift hill-streams, that form a connecting link between the wrens and the thrushes. They have the typical wren tail and activity, and a powerful song, but have a thrush-like size and beak. Although they do not have webbed feet, the dippers move about the bed of the stream searching amongst the stones for the aquatic insects on which they feed. Out of the water their amusing bowing or curtsying actions—each bow or curtsy being accompanied by a corresponding blink of the eyelids—attract the bird-watcher's attention.

The true thrushes—which include not only the common song and mistle-thrush—but also the blackbird, robin, chats and nightingale—are usually very vocal birds. They build cup-shaped nests, feed much on fruit, and are usually spotted at some stage of their life. Young blackbirds are dark brown and slightly spotted. Young robins lack the red breasts of their elders, and are also spotted. The thrushes have not less than twelve tail feathers.

Following the thrush tribe come the warblers. These are smaller, plainer, birds, and in northern Europe, they are mostly summer visitors only. Exceptions are the goldcrest, the Dartford warbler, and the hedge-sparrow, although the last is usually separated into a little group called the accentors. It is amongst the warblers that Nature has produced some of her greatest song-birds—the nightingales, the melodious warblers, the marsh-warblers, and the blackcaps. Most of these are woodland birds, hence their scientific name of *Sylvinnae*. Even the so-called garden-warbler is really a woodlander that receives its popular name from those old-time country house gardens that owned large plantations and copses. The European fan-tailed warbler is one of the reed-warblers resident in Mediterranean districts and is known by its tail. In Australia there is the pheasant-tailed warbler with the three central pairs of tail feathers greatly elongated.

WHAT IS A LAUGHING JACKASS?

The so-called laughing thrushes of China are really related to the babblers and to the beautiful-voiced American mocking birds, rather than to the true thrushes. As in the case of the laughing jackass or Australian kookaburra kingfisher (Fig. 25) their "laugh" is merely a call and is not at all associated with human laughter. The black-backed and black-headed gulls of our coasts are sometimes nicknamed "laughing-gulls" by the sailors, but here again it is not true laughter.

The starlings, which were formerly grouped near the crows at the beginning of the bird classification, are now given

Fig. 26. A young Starling. At one time starlings were classed with crows but now they are thought to be nearer thrushes. Notice the rear "perching" claw.

not narrow soft beaks as have the warblers, and they have ten wing feathers.

The nut-hatches, also with ten wing quills, have a longer and stronger beak, for they live on tree trunks and feed on insects and also on nuts, such as hazel cobs. These they break open by repeated hammering.

The shrikes are small perching birds with a curious little notch in the beak reminding us of the larger birds-of-prey. They catch beetles, small birds, mice and shrews. In time of plenty they impale their victims on the thorns near their hedgerow nests to make a larder, hence their nickname of "butcher bird".

The fly-catchers are specially equipped for their feeding habits by a development of hairs around the mouth. They repeatedly dart out at passing insects and return to the same perch, having no song and seldom any call. The swallows, swifts and nightjars (Fig. 28) also have many hairs developed around the gape to help to catch the insects they pursue on the wing.

The swallow family includes the martins and there is much confusion regarding these two birds among the uninitiated. They are easy to distinguish, for swallows build their mud-and-straw nests on the rafters or beams of outhouses and sheds, whereas house-martins build their mud cups against the walls under the eaves of houses, and sometimes in caves. Sand-martins burrow in sand and gravel banks, or use

a separate family nearer the thrushes (Fig. 26). They are upright walkers, however, and not hoppers as are the thrushes, and have nine wing and twelve tail feathers. As with the young storks and herons, starlings have the ability to clack their two mandibles together in song, and thus they produce the strange rattling background to their music. In winter, hordes of common starlings from North Europe flock into the British Isles and the Mediterranean lands. They roost during the night in great communal roosts in woods, or in city buildings—as in London at Charing Cross and elsewhere. Flocks travel from a wide area to use the one great central roost.

The titmice are agile little insectivorous birds. They include the acrobatic little blue or tomtit that swings upside-down on the garden coconut (Fig. 27). They have short conical beaks, however,

old river drains, as may be seen in many places—as, for instance, beside the Wye below Hereford Cathedral.

The swallows are known by their wide beaks, their long narrow wings with nine quills, and the forked tail with twelve tail feathers. On the other hand, the swift has ten wing and ten tail feathers, and as all its toes point forward, it cannot perch. From this we know that the swift does not belong to the swallow family although its flight in the air may suggest that it does. Actually it belongs to the next great order and is not in the perching birds at all, being more closely related to the nightjars and humming birds.

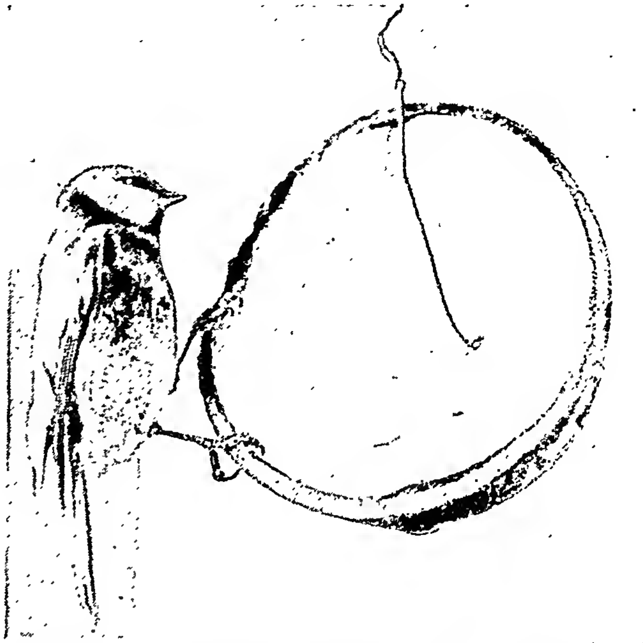


Fig. 27. A tit attacks a coco-nut hanging up outside a house. Tits are very adaptable and adventurous little birds and will try almost any kind of food.

Before we deal with these we may mention that at the end of the perching birds there is placed the famous Australian lyre-bird—one of the world's best songsters, with a lyre-shaped tail (3, Fig. 1)—and the gorgeous golden yellow, South American "Cock of the Rock", one of the most beautiful birds ever exhibited at the Zoo.

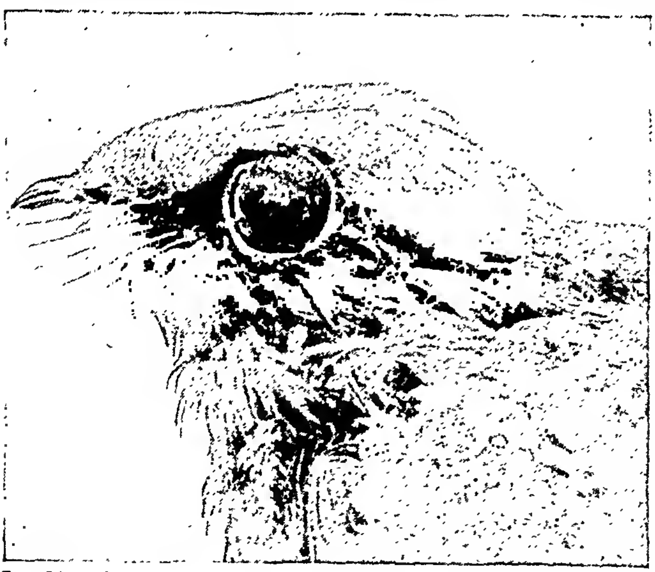


Fig. 28. A nightjar's head showing insect-catching hairs at gape.

Before dealing with the birds outside the great Passeres or Perching Bird Order, we should mention that their classification in this way does not mean that these birds never perch. Even the cormorant and the gulls will sometimes stand on a flat-topped tree or a big bough, but their feet are not of quite the same con-

struction as those of the true perching birds. For instance, there are the wood-peckers, usually hole-nesting birds with a specially extensive, brush-like tongue to lick insects out of the rotted bark. They also have a hammer-like beak with a perfect shock-absorbing skull so that they can hammer or drum loudly on solid wood as a spring sexual call—as in the case of the spotted wood-peckers of our own woods—or hack their nest holes in the trunks of rotten birch and ash trees.

Also, they possess stiff tails that help to support their bodies on the sides of tree-trunks like a tripod. To enable them to cling on to the bark, they have two of their toes pointing backwards. The wrynecks are a closely allied group of soft-tailed, woodpecker-like birds with remarkable long spiny tails.

THE TOUCAN'S BEAK

The honey-guides are famed in Africa for they are said to attract the attention of visitors and guide them to nests of bees so that they can feed on the grubs when the combs are torn out. Because they were believed to lay their eggs in other birds' nests, the honey-guides were first placed with the cuckoos, but their structure soon showed they were closely related to the wood-peckers.

The toucans of Central and South America always attract attention because of their enormously developed brightly coloured beaks. Although, as with the hornbill, their beaks seem to make the birds top-heavy by their size, actually they are remarkably light because they are pitted with air-sacs. The precise purposes of these enormous beaks is somewhat of a mystery, although it is believed that they have a combined feeding and courtship value.

The nightjars that make such curious rattling songs on a summer's night over our heaths and around the larch woods, may be likened to big nocturnal ground swifts. They form a close connection with the owls, the nocturnal birds of prey.

Owls, of course, are distinguished by the forward direction of their eyes and the discs of feathers around them to focus the scant twilight of the night on to the pupil. They have hooked beaks, strong claws for gripping their feathered or furred prey, and a dense plumage that is soft and ruffled. Other characteristics are their enormously developed ears and their feathered feet. Included in this group are the Indian fishing owls and the prairie burrowing owls.

The cuckoos as a tribe are known by their "zygodactyl" feet, with two toes forwards and two backwards. The great crested cuckoo of the Mediterranean lays its eggs in the nests of crows, while the American yellow-billed cuckoos make their own nests. The Indian koel cuckoo, or rain bird, mimics the mynah in its dark plumage and lays its eggs in the mynah's nest. The so-called road-runner of Central America is one of the ground cuckoos. It obtains its name from the speed with which it flies over the ground, as if running rapidly.

THE KINGFISHER'S DIET

The kingfishers have flat-feet with their toes ensheathed in a curious manner, three toes forward and one backwards. Our English kingfisher (Fig. 29) is widely distributed over Europe and Asia and will take gnats and other insects as well as fish. There are many Indian and Australian kingfishers that feed on reptiles, whilst the white-breasted kingfisher of Asia feeds on large insects and small lizards.

Such groups as the humming birds, the bee-eaters, the rollers, and the trogons, contain some of the most beautiful birds known. In the last

THE BEAUTIFUL KINGFISHER

Fig. 29. The kingfisher is found in every continent of the world. There are many species of kingfisher and most have a strong sharp beak (clearly shown above) used for catching fish. Some however, such as the kookaburra have broader beaks hooked a little at the tip. The kookaburra lives mainly on vermin and insects, though even it sometimes catches fish.

Fig. 30. The wood pigeon, a member of the extensive pigeon or dove family. The extinct Dodo was probably a dove. Pigeons can be distinguished by their beaks, swollen at the tip and covered with soft skin at the base.

mentioned group is a specially notable bird—the quezal of Central America, the beautiful metallic green colour of which recently attracted much attention at the Zoo. A further point of interest in the quezal is the enormous development of the wing feathers. These are so long that they trail back far below the tail and hang down like some great pheasant-tail.

The parrots, too, are often gorgeously-plumaged, especially the Rosella parakeet and the macaws. Despite their hooked beaks, they are mostly fruit-eating birds. They are arboreal and are good climbers, using their beaks to aid their climbing as anyone may observe in an aviary. All of them nest in hollow trees. The common little Australian grass parakeet, or budgerigar, now so popular as a cage-bird, is often misnamed the "love-bird". The true love-birds, however, are pretty and affectionate little African parrots about 6 in. in length with thick deep beaks without any ridge along them. The curious hanging parrots of India and Malay, with their thin, sharp beaks, are unlike the other parrot groups, for they hang suspended upside-down when asleep and even when resting.

Members of the pigeon tribe (Fig. 30) are easily identified by the swollen extremity to their beaks. Usually they have open nostrils and soft skin at the base. The flightless and now extinct dodo of Mauritius was a pigeon, despite its great size.

The auks are another big group of sea birds. They are mostly black and white birds—like the penguins, guillemots, razorbills, and puffins—and nest on cliffs or in holes. As they are without a hind toe they cannot perch and are upright walkers. The penguins, having lost their power of flight, have adapted their fore limbs as flippers for swimming. The penguins mostly seen in Zoos are the Cape or black-footed penguins of South Africa. They often nest in holes in rocks and lay two eggs. The larger king penguin, which lays only one egg and incubates it in the open, has bred successfully at Edinburgh Zoo.

The terns and gulls are included in a big family of grey-plumaged birds having their front toes webbed but with the first or hind toe free, and raised above

the others. The kittiwake is separated from the other gulls, however, because it lacks the hind toe—hence its name *Rissa tridactyla* or "three-toed".

RECOGNISING DIFFERENT GULLS

The flocks of gulls on the Thames and other waters may seem confusing at first, but a quick means of identification is to remember the colours of leg and beak. The small black-headed gull has red legs and beak. The kittiwakes have greenish-yellow beaks and black legs. The common gulls have greenish-grey beaks and legs; the herring gulls, yellow beaks and flesh-pink legs; the lesser black-backed gulls, yellow legs; while the great black-backed gulls have flesh-pink legs.

Woodcocks and snipe have such long probing beaks that they almost seem to be carrying a stick in the mouth (Fig. 31). The plovers have short bills, their nostrils are in grooves, and they mostly have wading habits on seashore or marsh, taking short runs along the ground from one spot to another.

The rails, which include the water-hen, are known by their long toes. The game-birds have compact, stout bodies, strong legs for running, and short round wings that are usually noisy in flight. The grouse tribe are distinguished from the others by their feathered feet, which are very conspicuous.

Of the diurnal birds-of-prey, the eagles, buzzards and hawks have short, round wings. They are usually high or soaring fliers, looking on the ground for their prey—rats, rabbits, hares etc. On the other hand the falcons have long, narrow, wings, giving swift flight,

Fig. 31. A snipe standing beside its nest. The snipe's bill, which is useful for probing for food, is so long that the birds look as if they were carrying a stick. Snipes are commonly seen in moorland districts, being characterised by their darting zig-zag flight.

enabling them to pursue their winged prey in the air. The lammergeier, or bearded vulture of the Alps and Himalayas, has sufficient strength to break the bones of a carcass in its beak and to feed on their marrow as does a dog. The vultures, however, are a family of large carrion-eating birds of prey, and except for the lämmergeier, have much of the head bare of skin.

BIRDS WITH TUBE-NOSED BEAKS

Although in the other birds-of-prey the females are the larger and more handsome sex, with the vultures the males are usually the larger of the two. Similar naked skin patches are noticed on the throats of cormorants, which family includes the darters and gannets, both fish-eating birds. The pelicans, too, are closely related to the cormorants, as are the frigate and tropic birds, some of the greatest of all bird fliers.

Herons (Fig. 20) storks, and ibises are easily known by their long legs and beaks, and it is interesting to remember that herons feed on other things besides fish—they probably devour more rats, voles, frogs, and water-shrews than eels. The storks of Europe are protected, being accounted of value because of their vermin-killing propensities.

The great groups of geese and ducks are usually known by their typical beaks, longish necks, and their wedge-shaped flying formations. The night-feeding of wild duck is believed to be a comparatively modern habit, arising from their persecution by wild-fowlers.

Coming to the end of bird classification we find such primitive forms as the petrels with their curiously tube-nosed beaks that seem joined together in pieces. These include not only the storm-petrels and shearwaters but also the albatrosses and fulmars. These, in their grey-and-white plumage, might easily be mistaken for gulls were it not for their fondness for gliding for great lengths of time.

There are also two great families of diving birds, the grebes or freshwater divers—that instead of having webbed feet have curious, fleshy lobes on either side of each toe—and the marine divers proper that have three front toes fully webbed. Each of these groups—as in the case of the auks—has very little visible tail—and the feet are placed well to the rear of the body to ensure deep and instantaneous diving. Finally, there are the flightless birds, the ostriches of Africa, the cassowaries of New Guinea and the emus of Australia. It is believed that their giant extinct relatives, the moas of New Zealand, were contemporary with the first explorers.

This similarity of bird-types in the three great southern continents, and the similarity of mammal types—such as the tapirs of South America and Malaya—are one of the great mysteries of science. It has given support to the theory that at one time in the not very distant past these continents were all joined in one great land mass.

CHAPTER 18

FISHES AND REPTILES

THERE is a very close link between fishes and reptiles, for, besides being scaly creatures, they have other things in common. It was from fish that the earliest amphibians developed. These "Labyrinthodonts" were half-fish and half-reptile, resembling, perhaps, gigantic frogs and toads. They inhabited the estuary swamps, spending part of their time on land and part in water. Even to-day our amphibians—the frog and the newt, for instance—spend their early life as free-swimming, fish-like tadpoles before they finally come ashore as cold-blooded, reptile-like creatures. Millions of years ago, when the Earth became drier and hotter, certain of these primitive amphibians stayed on shore altogether. They developed dry scaly skins, and became the ancestors of our present-day lizards and snakes.

Although the general description of a fish is a creature with scales and fins living in water and breathing through gills, this is not true for all. There are some fishes—the eel is one—that have no scales. Others—such as the climbing perch of India and the mud-skipper of West and East Africa—come out of the water and use their fins for locomotion. The mud-skipper is able to climb about the mangrove swamps because its moist tail is specially adapted to breathe the water in nearby pools.

In the more primitive sharks, rays, and sturgeons, the scales take the form of plates of enamel. Indeed, they are more akin to teeth than to scales as found in other fish. Ordinary scales are epidermal, or skin, growths, growing in rings much like the woody trunk of a tree. There is another resemblance to trees in that the rings show spawning-marks, and by counting them with the aid of the microscope it is possible to tell the age of the fish. Incidentally, the otoliths or ear-bones of a fish also enable us to tell its age in a similar manner.

We know that the sharks and rays are more primitive than other fish because their bodies are not so well developed, and they more closely resemble the fossil fish of the past. For breathing, instead of the usual gill-plate, or *operculum*, that covers the gills of a mackerel, cod or salmon, the shark has a number of slits in its neck. The even more primitive lamprey of the rivers has a number of holes, or punctures, through which the water passes and has no head bones—just a mass of tissue.

HOW A FISH BREATHES

A fish breathes oxygen, of course, but this oxygen is in solution in the water. When we see a fish constantly opening and closing its mouth, it is not really drinking, but is gulping in mouthfuls of water. This water flows over the gills and out of the neck, either under the gill-plate, or in the case of the shark through the slits of the neck. As it passes over the gills the oxygen is absorbed from the water by the blood-vessels in the gill-rakers. These are very numerous in order to present as large an area as possible to the water.

When a fish is taken out of water it dies, not because it has not enough oxygen, but because it is suffocated or drowned. There is no water passing over the gills to keep them open and the rakers collapse into a heap. Although there is plenty of oxygen in the air, the gill-rakers are in contact with it only

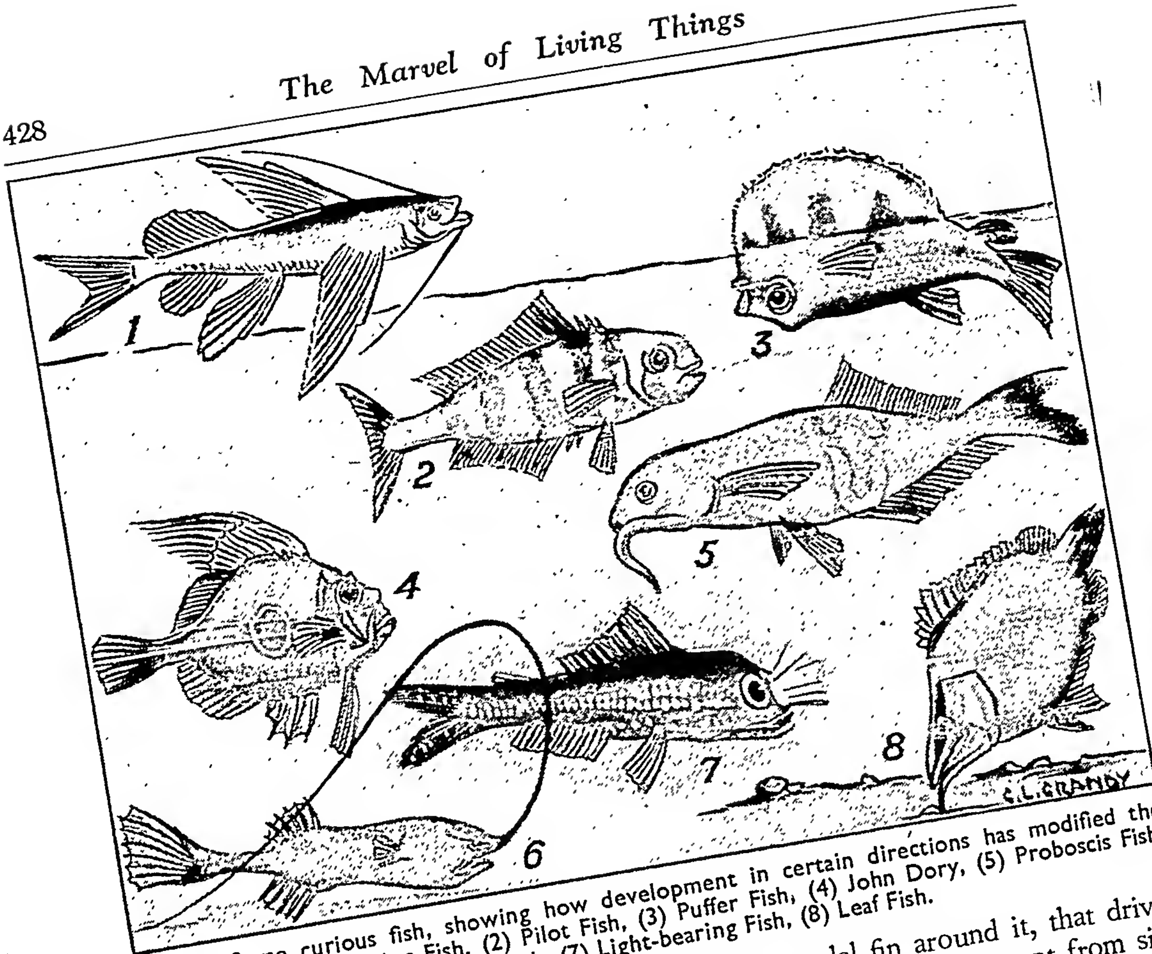


Fig. 1. Some curious fish, showing how development in certain directions has modified the original form. (1) Flying Fish, (2) Pilot Fish, (3) Puffer Fish, (4) John Dory, (5) Proboscis Fish, (6) Angler Fish, (7) Light-bearing Fish, (8) Leaf Fish.

through their too small outer surface.

A fish will drown if it is kept in water that lacks oxygen, as, for instance, in an aquarium tank that is over-crowded with more than about an inch of fish per gallon of water, or one that has the top of the water covered. That is why water direct from the main is not good for keeping fishes, and is best stood out awhile in the air. Aquarists grow pond-plants like *Vallisnaria*, *Sagittaria* and *Elodea* in the tanks because these plants give off oxygen in sunlight, thus aerating the water.

As the fins of a fish were originally the elements of the limbs of the earliest reptiles, we can expect them to correspond in position. They are chiefly used by the fish for balancing in the water, as we can see when the familiar goldfish are at rest. It is the tail, with its big caudal fin around it, that drives the fish forward when swept from side to side. Usually there is a dorsal fin on the back of the fish; two pectoral—or shoulder—fins, corresponding to our fore-limbs; two pelvic—or hip—fins, corresponding to our hind-limbs; and the anal fin. In some fishes—such as the stickleback and the perch—in which the rays of the dorsal fin are very strong and slightly projecting, they are used for aggression. In others—such as the great sail-fish of the Pacific—the dorsal fin is developed to an enormous size, and it is unusually large in the sharks.

In some of the angler-fish, a ray from the dorsal fin is so developed as to han over the gaping mouth of the fish as lies on the sand or mud (6, Fig. With an attractive tip, illuminated w phosphorescence in some deep-sea f

it lures small creatures to swim up to investigate, when they are immediately entrapped by the jaws below.

Some fishes—such as the carp, the loach, the North American catfish or "thunder fish", the barbel, and the chub—have tiny feelers, or barbels, projecting from the lips of the mouth. These always signify that the fish is a bottom-feeder, for it uses these barbels to feel its way along the bottom.

THE LOVELY ANGEL FISH

In the lovely angel fish from the Amazon, now popularly kept in tropical aquaria, the anal and dorsal fins are so well developed as to form an angel-like wing trailing down. To avoid any risk of breaking this beautiful but fragile fin against stones or the rough bottom of the river, the angel fish has the two spines of its pelvic fins developed to an enormous length and hanging down in front of these delicate fins. They act like the bumper in front of a motor car, shielding the fins from impact with any stones or twigs they should meet as the fish progresses through the water.

Most fishes have an air bladder, an offshoot of the intestine, that helps to adjust them to the varying pressures in their progress in the sea. If we look at the sides of a fish we see that in most of them the upper surface is dark and the lower surface light thus affording an efficient camouflage from foes above and below. There is a fairly well marked line dotted with nerve-centres however, and here the surfaces meet along the side. This is called the lateral line and is mostly concerned with maintaining the balance of the fish and the sensing of vibrations as it swims. (When a fish is killed, its balancing mechanism having been put out of action, it nearly always lies upside down or on its side as it floats on the surface.) African and Australian lung-fish have adapted this as a breathing organ, and in time of drought are able to live in holes in the dried mud.

The migrations of fishes—particularly herrings and plaice—have been carefully studied by marking them with numbered buttons and offering a reward for their capture and return. Most fish spawn in water and migrate to definite spawning places; but they move also in relation to their food. This usually consists of small crustaceans that in turn feed on the microscopic floating and animal life that we call plankton. They are subject to many influences, such as tidal currents, amount of sunshine, salinity of the water, and so forth, so that the study of the migration of fishes must include the study of all these other subjects.

MIGRATION OF THE HERRING

In this way the mystery of the migration of the herring shoals has been solved. The herrings appear off North Scotland early in the year. They gradually work down the east coast until they are off Norfolk and Suffolk by autumn, whence they pass round the Foreland to the Channel. This progression has been found to be due to the herring following vast numbers of tiny crustaceans, the *calani*, that are drifted by the currents until they often form enormous masses off the Dutch coasts and the shallow Dogger Bank. The *calanus*, in turn, feeds on the plankton that thrives in a good sunny summer.

The drift of currents in the North Sea crowds the young herrings and young plaice on to the Dutch coast. It has been suggested that if only these swarms of young fish could be transported to the less crowded waters of the Dogger Bank they would have a better chance of reaching maturity.

The vast numbers of these young fish result from the fact that prodigious numbers of eggs are laid by each fish—25,000 by the herring; 9,000,000 by the

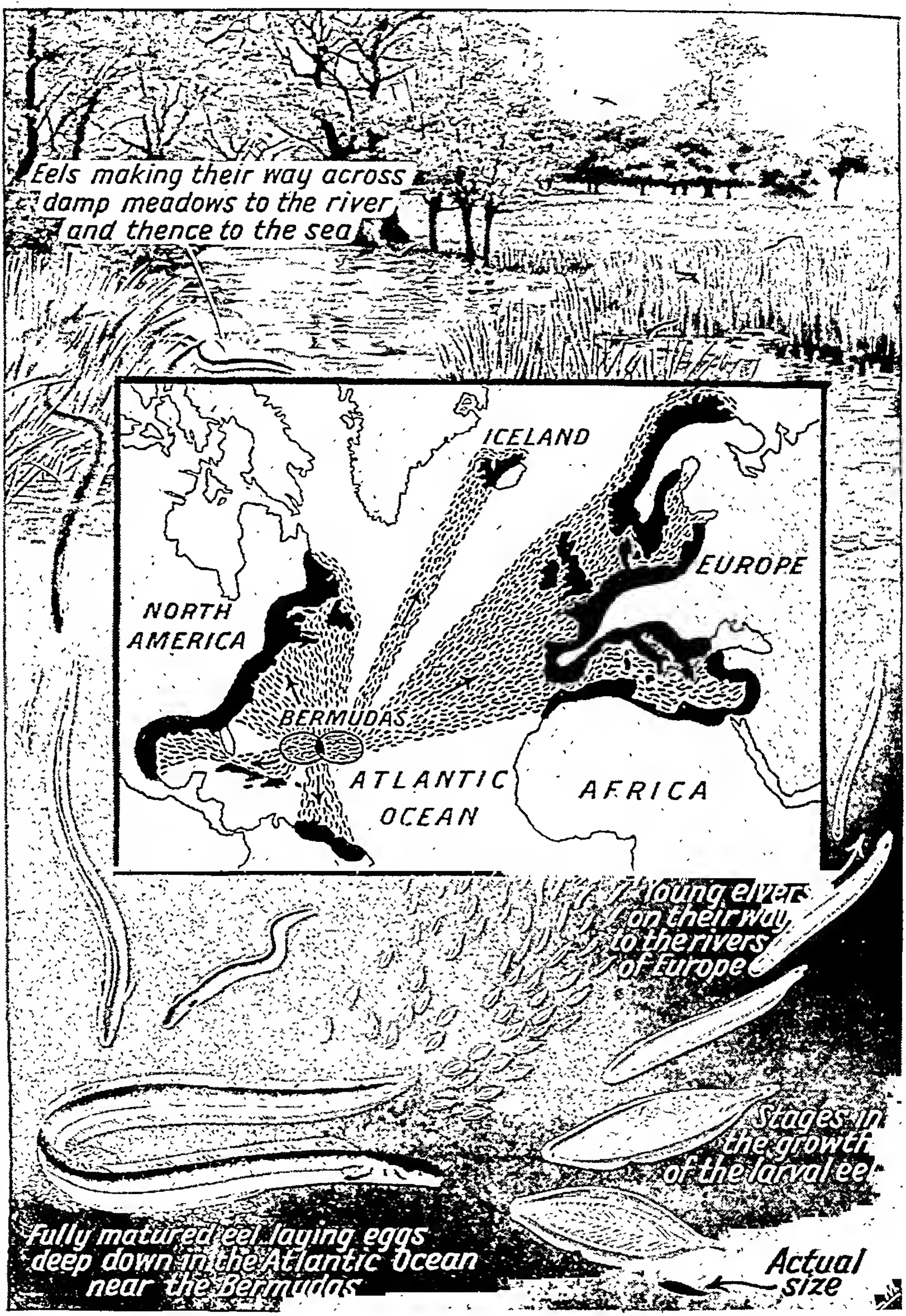


Fig. 2. The wonderful life story of the eel, which begins its existence in the weedy Sargasso Sea near the Bermudas, travels across to Europe with the Gulf Stream and returns to spawn.

Fig. 3. Two beautiful trout. Notice the adipose fin (characteristic of all the salmon species), a lump of fatty tissue on their backs.

cod; and 11,000,000 by the ling. Mortality is so great, however, that comparatively few survive to maturity. The turbot can produce nearly 9,000,000 eggs in the spawning season while some skates produce only a couple of eggs; yet in the sea, skates are commoner than turbot! The skate's egg and that of the dogfish are the "Mermaid's Purses" of the seashores.

Salmon marked in the Tweed have been traced to the Norfolk and Dutch coasts. One Norwegian fish even crossed the North Sea to Scotland. The bulk of the salmon that are marked in our rivers, however, return to the river of their birth.

Plaice-marking in the Irish Sea has shown that most plaice originate in St. George's Channel. As young fish they migrate northwards to spend their nursery days growing up on the sand and mud banks of the north-west coast of England, returning south again to the Channel to spawn. Most of our river fishes—such as the carp—go down to the deeper, muddier depths of the ponds and pits for the winter. At that time there is little inducement for the angler to turn out except for grayling and pike.

The wonderful migrations of salmon, from the pebble-strewn upper courses of the river of their birth down to the sea and back, are no more marvellous or mysterious than the journeys of that primitive river fish, the lamprey. With its sucker-like disc the lamprey often fastens itself to the side of a salmon in the river, or to a shark in the sea.

We must mention the story of the eel (Fig. 2), hatched in the dense weed of the Sargasso Sea, in the south-west of the North Atlantic. Migrating as a young eel, or elver, with the Gulf Stream across the North Atlantic, and then up our rivers and even over the damp fields at night, it grows to maturity in ponds and brooks, lakes and reservoirs. It then goes back to the sea, crosses the Atlantic against the Gulf Stream, and finally spawns in the Sargasso Sea where it dies. The American and European eels, spawning in that dense mass of weed, never lose their way—always as youngsters they migrate to their respective Continents.

In Britain we have thirty-three freshwater fishes, the best known of which are the salmon and the trout. Between these two there is often much confusion. Although the trout is usually well-spotted

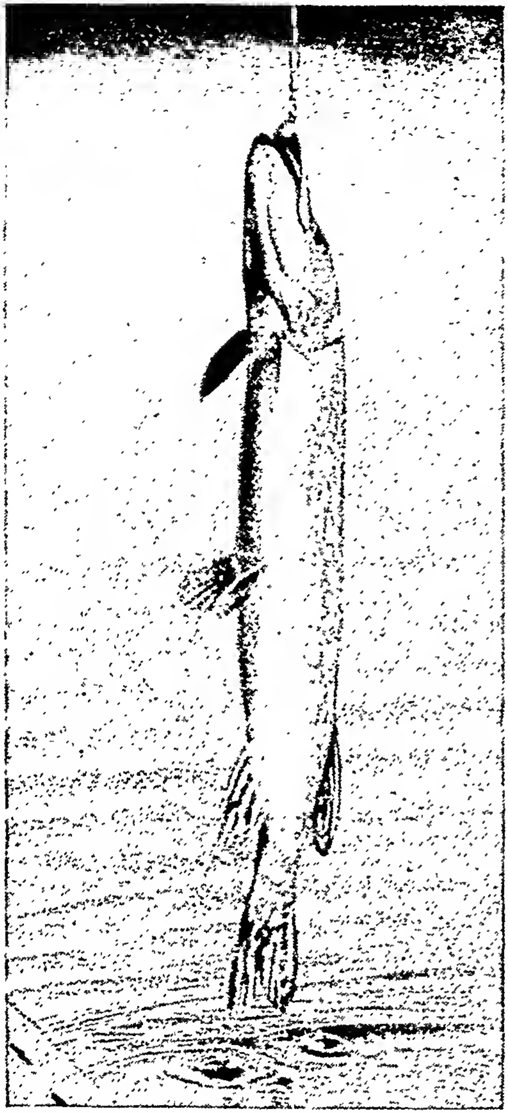


Fig. 4. A fine young pike. Pike, which are often known as Jack Fish, are among the most ferocious of fresh-water fishes and do tremendous damage to trout.

and smaller, all the salmon tribe, (which includes trout, char, and grayling) have a little lump of fatty tissue, called the adipose fin, lying on the back behind the dorsal fin (Fig. 3). The number of scales lying side by side in a line on the side from the lateral, or medial, line to the adipose fin, is twelve or less in the salmon, and fourteen or more in the trout.

The grayling is a river-fish with a curious lattice-like patterning of its scales.

The pike and the perch are the most ferocious of our freshwater fishes. The former is dark grey-green, with a long nose (Fig. 4). It kills large numbers of young ducklings and small aquatic creatures, and will even attack bathers. The perch is much shorter and deeper in the body, and is marked with dark vertical bars.

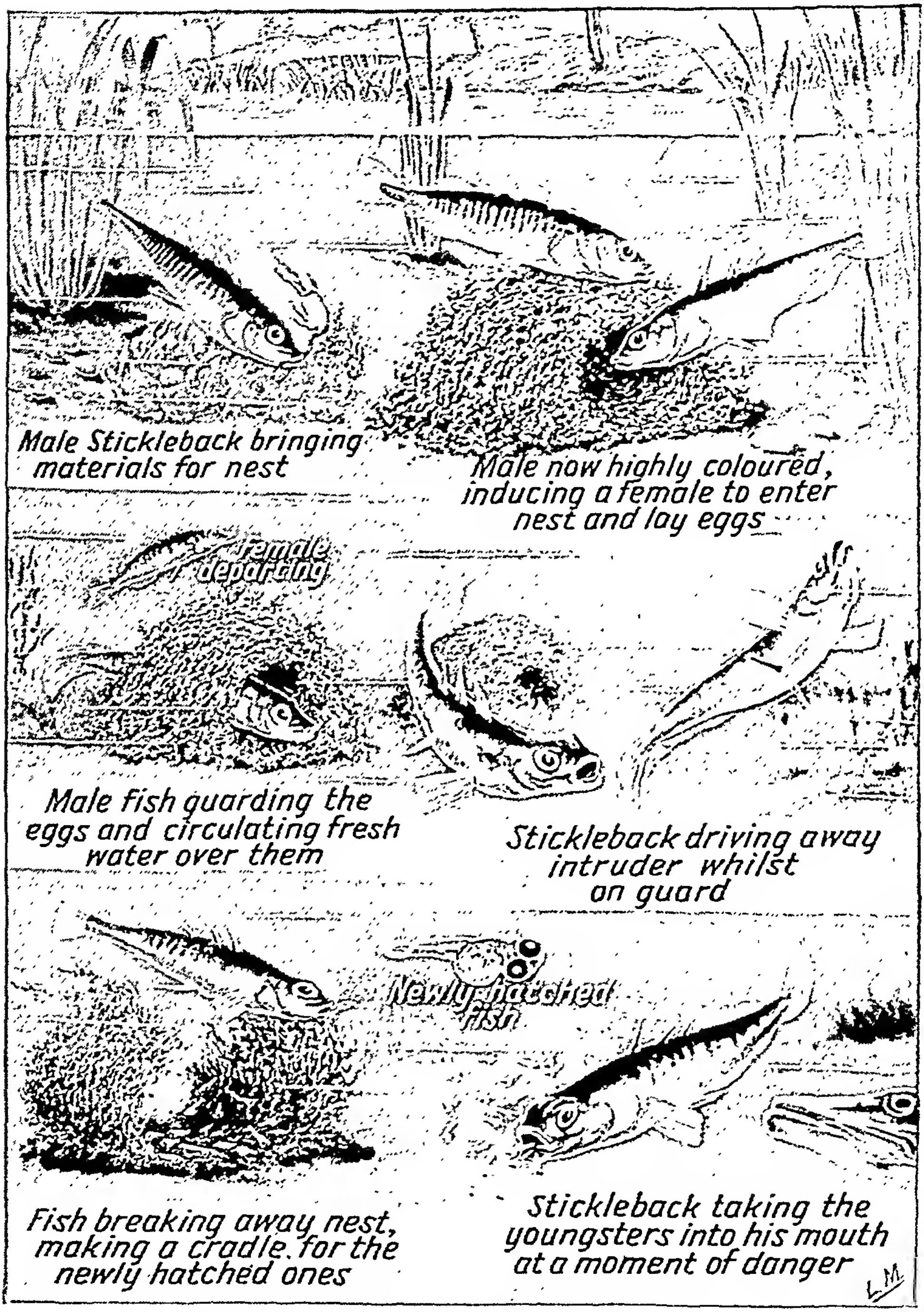
Amateur anglers often confuse the rudd, or "red eye", with the roach, a small fish usually found swimming in schools with the silvery dace. In the rudd the dorsal fin is never directly above the ventral fins, or in the middle of the back, as it is in the case of the roach, but is placed nearer the tail.

The bleak is a small silvery fish that inhabits clear, swift streams.

STICKLEBACK'S LIFE STORY

The little 3-spined stickleback (Fig. 5) –the "jack-sharp" or "tiddler" of the schoolboy—is one of the most interesting fishes in our ponds. As in the case of some other fishes, it makes a nest. In spring when the fish spawn, the male stickleback takes on a handsome red colour, from which he is given the North country schoolboy's nickname of "doctor". He bites off pieces of pond-weed to make a little nest amongst the weeds. In this nest, which is shaped like a barrel open at each end, the female stickleback lays her eggs and the male sheds his milt over them in order to fertilise them.

His mate then takes no further interest in them unless she tries to eat them, but he mounts guard, fanning his fins to keep a constant current of fresh water moving over the precious eggs. Should any other fish dare to approach too near, the stickleback charges, and will probably rip open its belly with the sharp spines on his back. When the young hatch,



LIFE STORY OF THE VALIANT STICKLEBACK

Fig. 5. The Stickleback, "Jack Sharp" or "tiddler" is one of the fishes that make nests. The male guards the nest like a nurse-maid seeing that none of the youngsters is gobbled up.

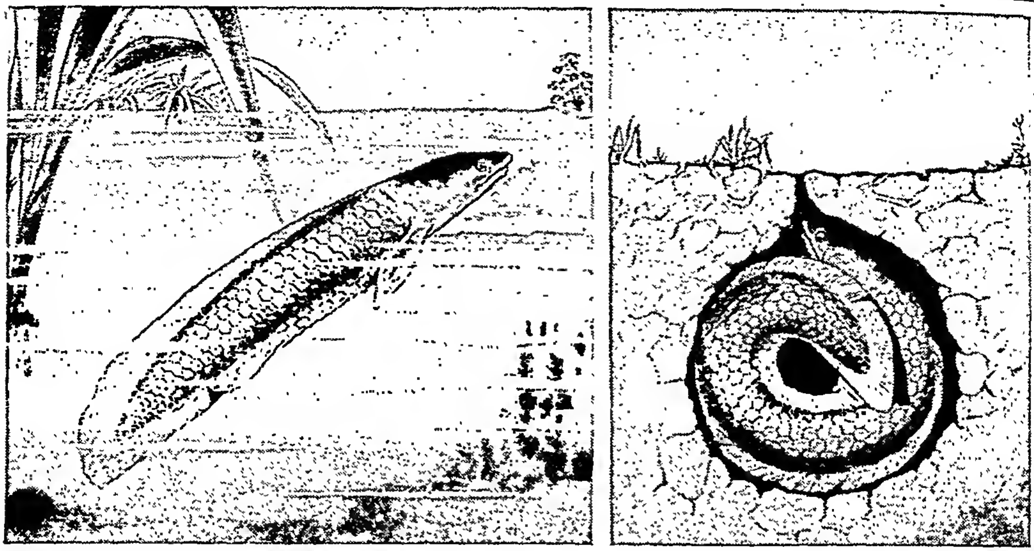


Fig. 6. The lungfish at normal seasons (left) swims about, but when the water dries up it makes a nest (right) in the mud and remains there, breathing through a hole.

the male breaks away the upper part of the nest to leave a mere cradle-like structure for them. Should any fry stray too far from home he merely follows, sucks them into his mouth, spitting them out again into the nest! The life story of this interesting little fish is illustrated in Fig. 5.

FISHES THAT BUILD NESTS

There are other fishes that make nests—as for instance, the fifteen-spined stickleback of our coasts that builds near piers and in ropes suspended in the sea. In the muddy streamlets of the sugar marshes of Guiana, the Hassar, one of the Silurid fishes of tropical America, makes quite well-formed nests of grass blades and leaves.

Another marvel of fish-life is the freshwater bitterling that, by means of a long ovipositor, lays its eggs inside the shells of freshwater mussels. The male Chinese paradise fish sucks in a mouthful of bubbles and carries them below the surface to a nest under water. After the female has laid her eggs he puts them inside this nest of bubbles for protection. The lampreys clear a portion of the bottom of a stream, and, by removing stones upstream, so disturb the sand as to cause it to be washed over their eggs, so burying them. The salmon makes a shallow trench, or redd, in which it deposits its eggs. The North American butterfish lays its eggs in an old oyster-shell, the female coiling herself around them to keep guard. This is an unusual procedure, for any "mothering" after the eggs are laid is usually done by the male fish. Sand-gobies also use empty shells for egg-nests. The small bowfin of North America bites off bits of weeds until it has made a clearing in the river vegetation. He brings the female fish through the narrow entrance and here she lays her eggs, after which the male guards the nest and its contents.

Fishes are the only group of vertebrates, or backboned animals, that have no true neck, for they have never had cause to develop one.

Some fishes are endowed with the power to make mysterious noises. Sea fishermen have often heard the bark of the conger eel. In the Indian trigger fish a sonorous sound is produced when certain bones connected with the swim

bladder are rubbed together. The gurnards make a rattle-like noise with certain bones in the head. The megrim fish of our coasts can purr and buzz. Coffer and globe fish can growl. The Amazonian *Lepidosiren* emits a deep growl; the Australian *Ceratodus* can be heard to growl when it fills its lungs at the surface. The Egyptians called the horse-mackerel the "Snorter" because it can grunt like a pig. The little sea-horse—one of the pipe-fishes with a curious prehensile tail with which it clings to seaweeds, a horse-like head, and a quaint upright swimming motion —is said to make a noise like the distant beat of drums.

Incidentally, too, the male seahorse carries its eggs in a pouch beneath the tail after hatching. The fry stay near their parent for a while, darting like young kangaroos into the pouch in time of danger or emergency.

THE CURIOUS LUNG FISH

The curious African and Australian lung fishes (Fig. 6), already mentioned, can breathe both air and water. They come at the top of the fish world, and seem to form a connecting link with the reptiles. At the other end of the scale are the curious lampreys, the hag-fish, and the sea-squirts. They start their lives swimming in the sea like little tadpoles, but finish as skinny bags, clinging to the rocks, with two siphons to inhale and exhale water.

Some fishes have the extraordinary attribute of being able to change their sex. Among these is the common sword-tail to be seen in many aquaria. It is so named from the prolonged sword-like lower ray of its tail-fin—probably part of its courtship display, for it is used for no other purpose. Another is the scorpion fish (*Sebastes*) of Madeira.

We have already mentioned camouflage in fishes. This is particularly evidenced by the leaf-fish of the Amazon (8, Fig. 1); this, like certain tropical butterflies, is shaped and patterned exactly like a leaf. Its enemies are deceived by its resemblance to the dead leaves that fall into the water.

BRIGHTLY COLOURED FISH

We generally think of fish as only silvery or dark greenish-blue creatures. Many people are surprised to learn that they sometimes attain gorgeous colours, as in the red fire-fish, some of the gurnards, the fighting fish of Siam, and the coral fish. In the Tortugas are wonderful coral formations, the beauty of which is enhanced by shoals of fish of glorious hue. These have been observed and photographed by means

Fig. 7. An under-water photograph of a school of grey snappers swimming among the coral.

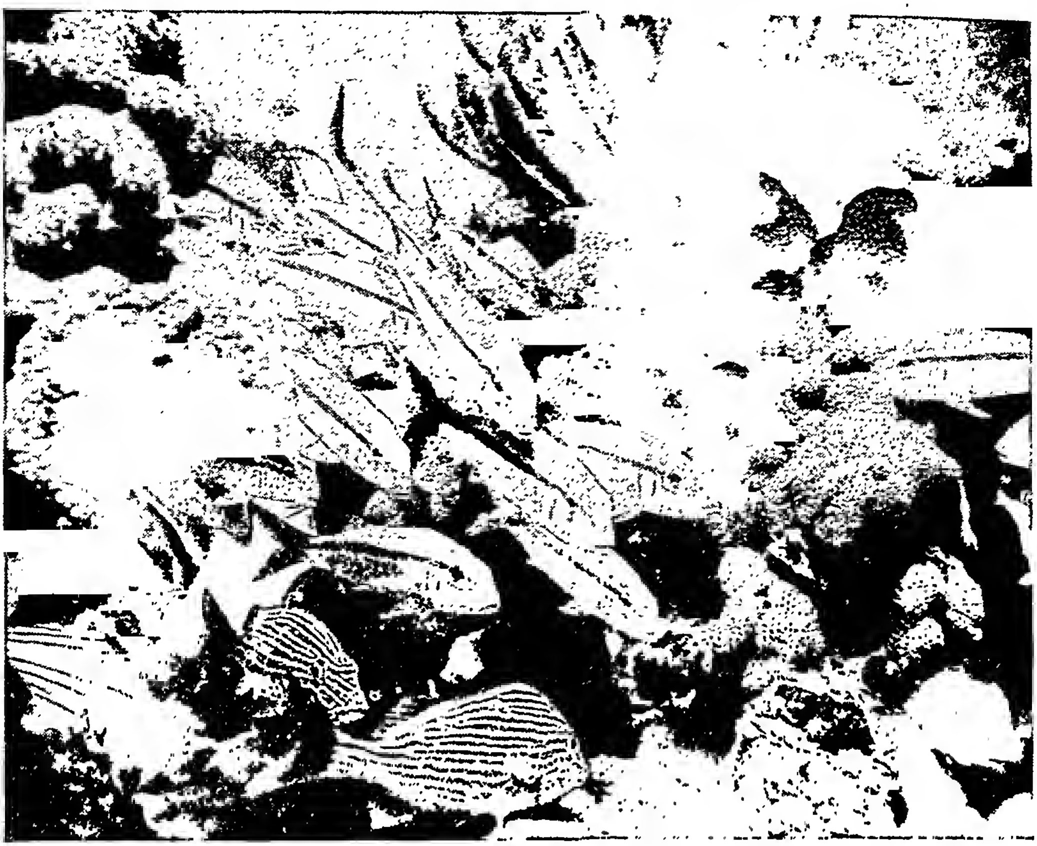


Fig. 8. Some of the gorgeously coloured, tropical fish found in the Tortugas among the coral at the foot of the reef. (Above) the Yellow Goat-fish and (below) the Yellow Grunt.

of deep-sea observation chambers equipped with all the necessary apparatus for a prolonged stay at great depths. They are shown in Figs. 7 and 8.

SEA'S FIERCEST INHABITANT

The sword fish (1, Fig. 10) of the Indian, Pacific, and Atlantic oceans are amongst the most predatory and savage creatures of the sea. Their jaws are prolonged into long, tapering, serrated swords, and in British specimens 11 ft. in length, the sword is about a yard in length. They chiefly feed on cod and tunny (4, Fig. 10), stabbing with their swords, but sometimes they even attack whales in the same way.

Perhaps the most dreaded of all fishes, however, is the *barracuda* (2, Fig. 10) of the South and Central American coasts, with its ferocious mouthful of gruesome teeth. A contrast to these fearful creatures is afforded by the mysterious pilot fish of the oceans (2, Fig. 1). It was regarded as sacred by the ancients, who believed that it guided them towards land, disappearing when the latter was approached; they also believed that its presence warned bathers of sharks. It is remarkable for its rounded belly and deep blue stripes, and to-day it continues its habit of acting as a pilot to both ships and sharks.

The John Dory (4, Fig. 1) contributes much to the trade of the fish-and-chip dealer of the English industrial towns. It is of a burnished golden colour with a dark brown patch on each side, this being said to be the imprint of the hands of St. Peter when he took the tithe money from

the fish! The John Dory is always an interesting object in the aquarium, as at Plymouth, because of its telescopic mouth that has the uncanny capacity of suddenly engulfing a prawn that is swimming far out of normal reach. Other "fish-and-chip" fish are the megrim or witch fish and the monk fish. Both these strangely-named fish usually appear in commerce under the fancy name of "rock salmon".

BIG GAME FISHING

The tunny (4, Fig. 10) has become famous in the years since 1928 by the fact that it now migrates annually from the Mediterranean into the North Sea in late summer, so providing "big-game fishing" for a few enthusiastic sportsmen. It comes in increasing numbers, probably because of a change of currents bringing warmer water into the North Sea. It is really a giant mackerel that feeds on flying fish and on the herring and pilchard shoals. Related to the tunny is the curious sucking fish, with a sucker-like disc on its head by which it clings to the under-surface of sharks (Figs. 11 and 12) and feeds on the scraps left from their meals.

The weevers, or "sting-fish", of our coasts have sharp, poisonous spines on the gill covers and on the first dorsal fin. By these, painful wounds may be inflicted on bathers who tread on them.

Neither the flying gurnards (1, Fig. 1) of the Mediterranean and tropical oceans nor the true flying-fish (Fig. 13) "fly" in the strict sense of the word. When pursued by their enemies they have the power to leap far out of the water and to sustain their movement through the air for a considerable glide by the use of their large pectoral fins.

The curious fighting fish of Siam are relatives of the perch. The natives use them for prize fights, wherein the fish charge and counter-charge, and, as they do so, increase the brightness of their lines. Ultimately one fish is vanquished and, retreating to the corner of its jar, loses its vivid colouring. Strange to

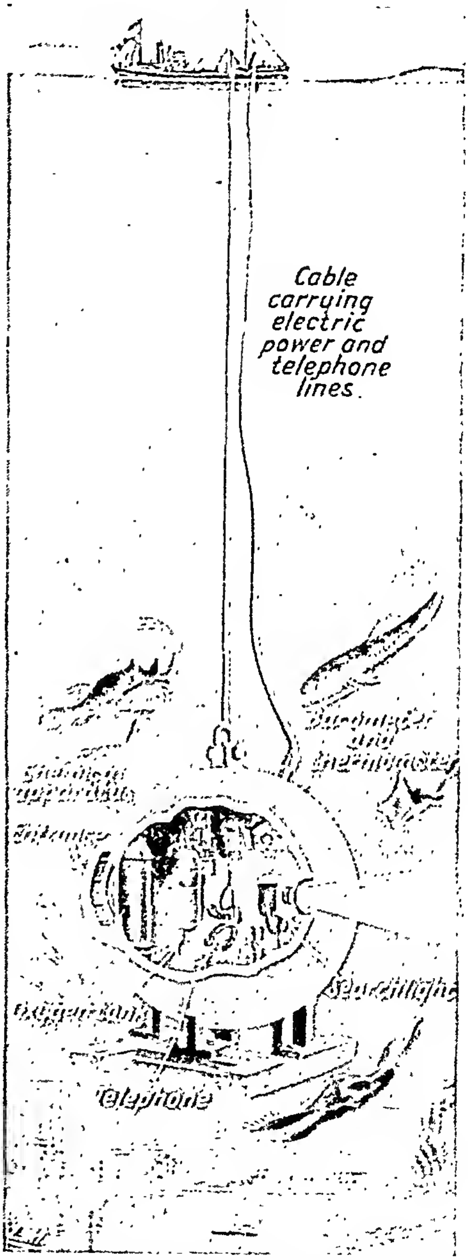


Fig. 9. Beebe's "bathysphere" or deep-sea observation chamber by which descents for observing tropical fish have been made to 3,000 ft.

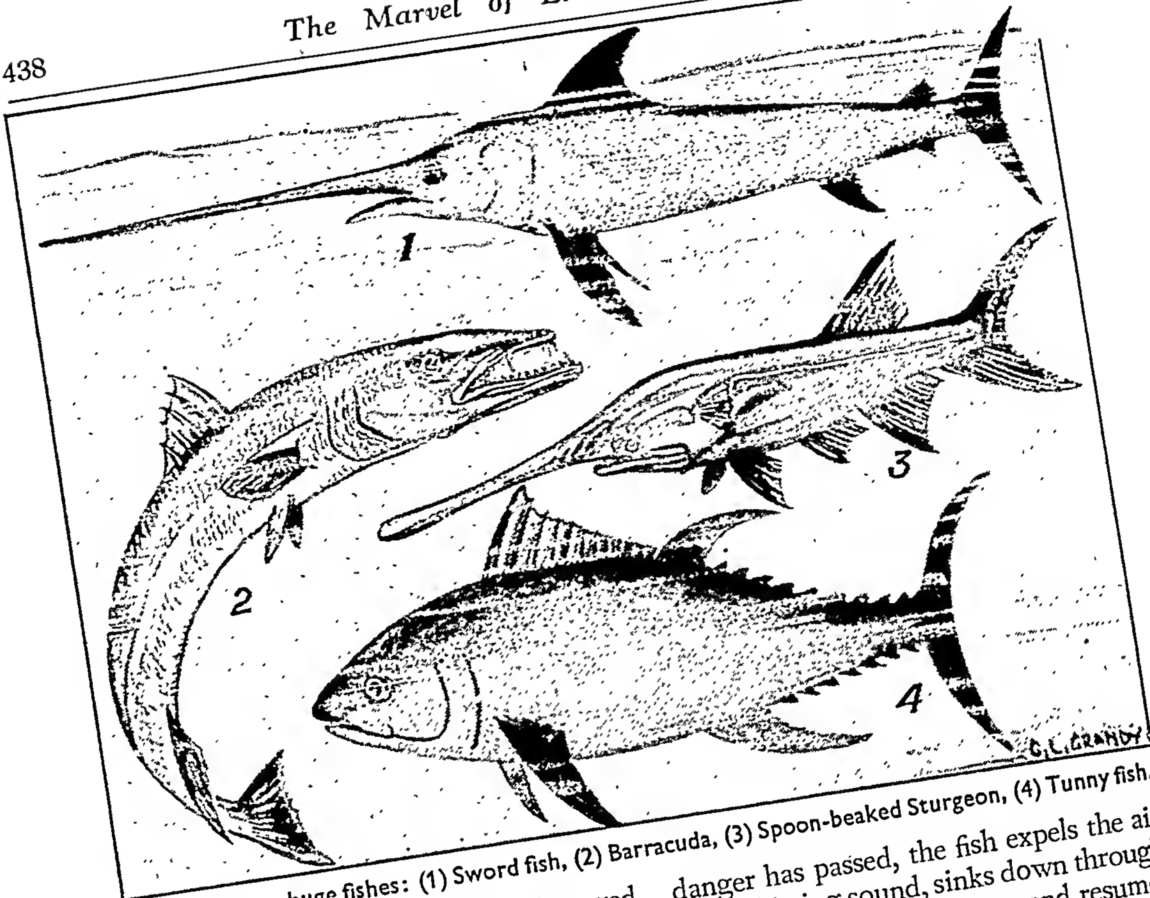


Fig. 10. Some huge fishes: (1) Sword fish, (2) Barracuda, (3) Spoon-beaked Sturgeon, (4) Tunny fish.

say, neither fish seems to get damaged in these combats.

The ribbon fishes derive their name from their very considerable length (see Fig. 6, page 374). They usually inhabit deep water at sea, and some think that their rare visits to the surface may have given rise to many of the apocryphal "sea-serpent" stories.

THE SEA HEDGEHOG

The globe or puffer fish, or sea-hedgehog of Indian and West African waters, have the curious habit of inflating the body with air until they assume a globular form. This appearance, coupled with the erection of their spines, gives them a grotesque hedgehog-like appearance. When alarmed they rise to the surface and float upside down, like a boat sailing ...ind (3, Fig. 1). When the danger has passed, the fish expels the air with a hissing sound, sinks down through the water, lowers its spines, and resume its normal condition.

The familiar plaice and flounders our coast have a marvellous life-sto They do not start life as flat fish but fish of ordinary shape. Gradually eye begins to grow round to the o side, and the fish tends to be more more on its right side. When it rea the adult stage both eyes have wo round to the one side, and one s white, while the other side is dark brown. In the plaice this is sp We may suppose that these flat fis their dark sides as their backs a white underparts as their bellies position of their fins and tails that the dark and light surfaces a their two sides that have flattened to suit a life on the

of the sea. The skates and rays also are flattened fishes, but in their case there is no delusion about backs, for they are not flattened sideways.

Some fishes attract attention because they are charged with electricity, and can inflict electric shocks. In New York Aquarium the discharge of an electric eel has been made to light a neon tube. This fish (Fig. 12) which comes from the Amazon, is one of the most dangerous of nature's electricians. It has a series of superimposed electric plates along its 6 or 8 ft. body, and with them it kills fish for food and protects itself from dangerous enemies.

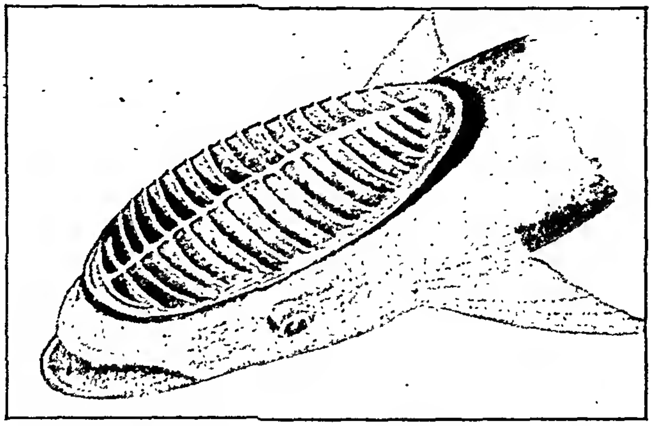


Fig. 11. Head of the sucker fish. The sucker is used for clinging to a shark's belly. Sucker fish are related to the tunny.

WHAT IS A TORPEDO RAY?

The electric or torpedo ray, sometimes found in British waters, has two kidney-shaped organs on each side of the head. Each is composed of from 300 to 1,000 hexagonal prismatic columns arranged side by side. Each column in turn consists of about 500 superimposed plates or discs, separated from one another by albuminous liquid, and resembling the Voltaic pile mentioned earlier in this book, in our chapter on Electricity.

Each column is plentifully supplied with nerve cells, a rich plexus of nerves entering on one side and dividing into a large number of finer nerve fibrils. These penetrate the deeper substances of the plates and end blindly. When the fish is annoyed, the innervated surface of each plate becomes galvanometrically negative to the other surface, an electric current being produced that

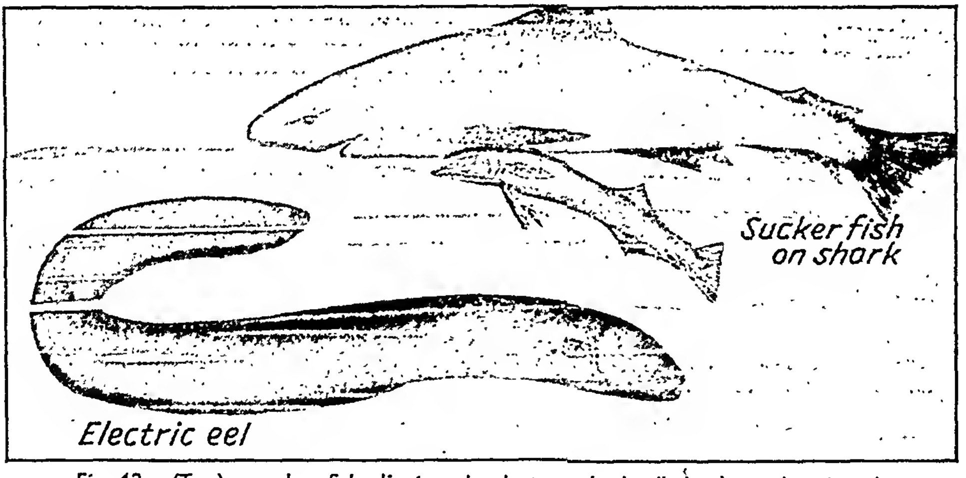


Fig. 12. (Top) a sucker fish clinging closely to a shark; (below) an electric eel.

Fig. 13. Some curiosities of the sea; fish that fly, skip and climb.

gives out a shock similar to that from a Leyden jar.

Even the common skate of our coasts gives a feeble discharge, although it is not known to affect other fishes. The small African thunder fish of the Nile and Congo is another dangerous electrician, having some four million electric plates scattered over its body skin. The little North American star-gazer has a small electric battery behind each eye. It gets its name from the position of its small eyes on the top of its head, making it impossible for the fish to look sideways.

FISH THAT SHINE IN THE DARK

The mysterious cold lights of the sea—the phosphorescent fishes—have been studied intensely, for there are many of them. These lights waste no energy in producing needless heat, and their origin is probably similar to that of the glow-worm, the luminous centipede, and the firefly, in that it is a biological combustion or oxydisation. Research has shown this cold light of the deep-sea fishes, which often studs their bodies as with little white lanterns, is due to two substances, *luciferin* and *luciferae* The former is the fuel burned for th light, and the latter a kind of fermen necessary for the work but not itse changed in the process.

The first light-bearing fish w dredged from the ocean depths in 18 A little black fish marked with m round white spots, it was named *My phum* (supposed to mean night-lig Not until some time later was it fo that these white spots are cold lights mark the fish in the black depths. luminous spots are called *photospo* light-bearers, and later studies shown that these luminescent fish in all the ocean depths at 1,500 f or so (7, Fig. 1).

We have already mention

angler fish (6, Fig. 1). These fish live in the deep seas and have the first dorsal fin modified into a kind of fishing rod. At the tip is a light that acts as bait to lure inquisitive fish near enough to be snapped up. Some deep-sea fishes have luminous spots due to light-producing bacteria, resembling the phosphorescence we see on dead and decaying fish. None of these luminous fish have any other title than their long scientific names, for it is only in modern times that they have at last found their way into the natural-history books.

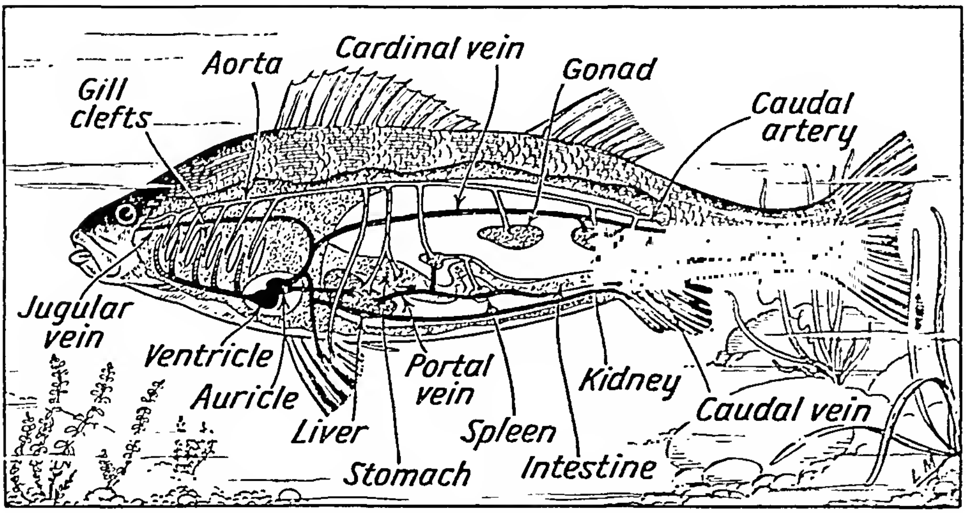
A "FOUR-EYED" CREATURE

A curious four-eyed loach-like fish of tropical America at first appears to have four distinct eyes, but on closer examination these are found to be only two. Each is divided into halves, however, one for seeing above water and one for seeing below water as the fish swims along the surface. To make this eye a success it has been necessary in the long story of evolution for two distinct lenses to be formed in each eye, because of the different refractive properties possessed by water and air.

These "Two Eyes", *Anableps*, are closely related to the famous "blind" fish of the Kentucky and Indiana caves. These fish have lost all trace of their eyes through generations of life in the dark subterranean waters. A similar loss occurs with the little *proteus*, a salamandei amphibian of the Dalmatian caves.

Close to these fish in classification come our ordinary pike, and then the curious African beaked-fish or elephant-fish, in which the lower jaw is prolonged into a beak or trunk (5, Fig. 1). The primitive bony pike of North America has peculiar quadrangular, ganoid scales. It is one of the few lowly fish forms that have a completely ossified skeleton, the lowest fishes like the sharks and rays having no membrane bones.

The common toothless sturgeon is well known and still strays to such British waters as the Severn and Trent. The spoon-beaked toothed-sturgeon (3, Fig. 10) of the Mississippi has its upper jaw developed to an enormous spoon-like beak, reminding us forcibly of those African tribes who enlarge their lips by inserting wooden discs in them.



The anatomy of the fish. Fishes (*pisces*) form a class of the *Phylum chordata*. They all live in the water and all except the Lung-fish and mudskipper breathe only through gills.

(1) Basking, (2) Hammerhead, (3) Thresh

The sharks and rays are a large group, some fifteen different species occurring regularly in British waters. The two spotted dog-fishes are a great trouble to inshore fishermen, while the basking shark (1, Fig. 14) is fished commercially off western Ireland and for sport off western Scotland. The blue shark, or beagle (4, Fig. 14) and sometimes the thresher (3, Fig. 14), are seen in British waters every summer. The latter receives its name from its habit of rounding up shoals of fish by threshing the water with its tail. This has a very long fin, and the fish are frightened into a mass into which the shark can charge and secure an ample quantity with ease.

THE FAMOUS BASKING SHARK

The big, basking shark, which basks on the warm surface waters with only its dorsal fin breaking water, often attains a length of 30 ft. If gashed by the propeller of a passing liner, it is sometimes washed ashore and almost invariably hailed as a whale, although the gill-slits in the side of the head and vertical tail clearly show it is not a mammal. The hammer-head shark has an enormous hammer-like head with eyes at each end (2, Fig. 14). Though small specimens have been taken in British waters, the really big ones, famous with big-game anglers, inhabit the Caribbean Seas and the Pacific. In places such as Aden, where sharks are common, it is surprising that dark-skinned natives can swim and dive fearlessly although white bathers are quickly caught.

Related to the sharks and rays are the saw-fishes, not to be confused with the sword fishes mentioned previously. In their case, the prolonged jaw has rows of large, sharp projecting teeth like a very coarse, double-bladed saw. They inhabit the warm waters of the Atlantic and the Mediterranean, growing to about 20 ft. in length and having a saw up to 6 ft. They use this weapon by striking sideways in the water, and are so strong that in the Indian estuaries they have been known to cut bathers in two.

The immense popularity of modern aquarium-keeping has introduced to English homes the brilliant beauty of many tropical fish. Among these is the *Neon tetra* with its brilliant crimson, bright emerald green, and silver; and the angel fish with its black stripes. The various varieties of goldfish are domesticated forms of the carp. This fish is not native to our ponds, but was imported from Asia. Young goldfish hatch greyish-black, like their carp ancestors, affording yet another example—or "recapitulation", as it is termed—of the evolution of a creature as shown in its early development. As they grow they gradually acquire the golden colour that makes them so attractive. A number of goldfish introduced to the waters of Siam to improve them soon reverted to their ancestral carp form, or were ultimately bred out. On the other hand, in the "shubunkin" varieties modern fanciers have even tinted the goldfish with blue. The goldfish is one of the few animal forms in which freaks have bred extremely true to type.

ARTIFICIAL MIGRATION

As with the birds and beasts, so with the fish. Man has upset the natural distribution by bringing Asiatic carp to British waters and taking British salmon to Australia and New Zealand, and the American black bass to South Africa.

Because of its sporting qualities, too, the rainbow trout has been sent from Yellowstone Park, U.S.A., all over the world (Fig. 15).

In Germany and at Plymouth, experiments have been carried out to train fish. The fish were found to respond to the

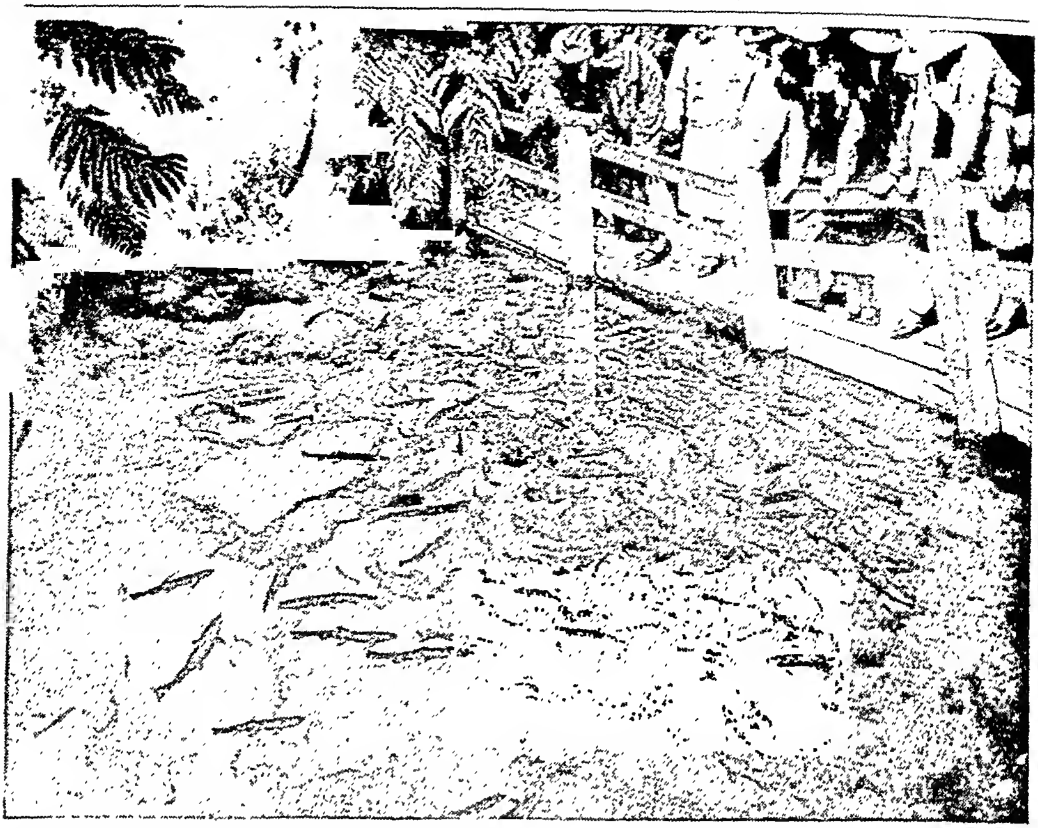


Fig. 15. Rainbow trout, originally imported from U.S.A., at Fairy Springs, Rotorua, New Zealand.

note of a tuning fork sounded in Lower C, and to proceed to a regular spot for their food. In other experiments blennies reacted to changes in temperature and salinity. Wrasses were found to be able to discriminate between one or two sources of light, and between monochromatic—red, green, yellow and violet—lights. The fish were attracted by an electric buzzer sounding a note F in the second octave, or by a tuning fork sounding lower C. To test their powers of discrimination, further discs, squares, triangles, and letters of the alphabet were used. Thus we see that the study of the unsolved mysteries of fish life is to-day a good deal more than what Dr. Johnson likened to "a line with a worm at one end and a fool at the other!"

The reptiles with their naked-skinned allies, the amphibians or batrachians, are an equally important group of scaly animals. They are more highly developed than the fishes and have taken to a life on land. The possession of scales is not always a sure guide to the "nature in the beast", however, and the reptiles or "creepers" still retain from their fish ancestors the habit of relying on their tails for propulsion and their limbs for balance. When in a hurry a lizard obtains most of its speed by swinging its tail from side to side, merely using its legs to support its body. On the other hand, the snake glides on its ribs, as it were. Its skeleton shows an enormous development of ribs along its body, while its original pair of lungs is reduced to one.

Except for traces of leg bones in the Indian boa constrictor and python (Fig. 16), snakes have lost their limbs. If we look at a snake we see that whereas

the scales of its back are arranged in typical overlapping fashion, those of its belly are like the rungs of a ladder. Each scale is keeled to the edge of a rib and raised a little by movement through its ribs, which turn the scales and enable them to grip. The snake has its jaw bones joined by such elastic ligament that it can swallow prey that is actually considerably larger than its mouth cavity. Not all snakes are poisonous, for many—like the boas—are constricting snakes. They twine their bodies around their victims and crush them to death. Some of the better known snakes are illustrated in Fig. 17.

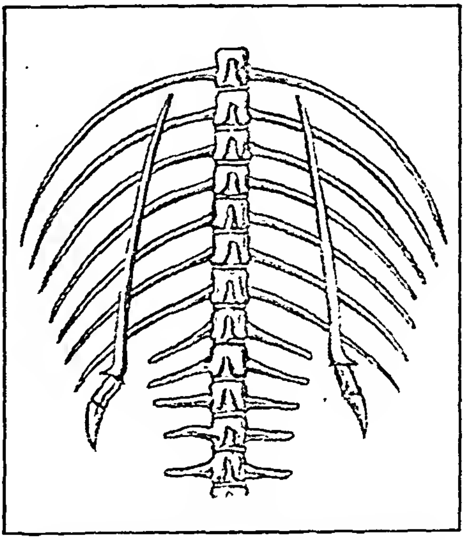


Fig. 16. Skeleton of a Python showing rudimentary hind limb (ventral surface).

Poisonous snakes do not sting, as many people imagine, nor do they use their forked tongue to harmful effect. Most of the older artists drew snakes' heads very incorrectly, showing the mouth opened too wide. When we watch the snakes at the Zoo, we can see that they slip the forked tongue between

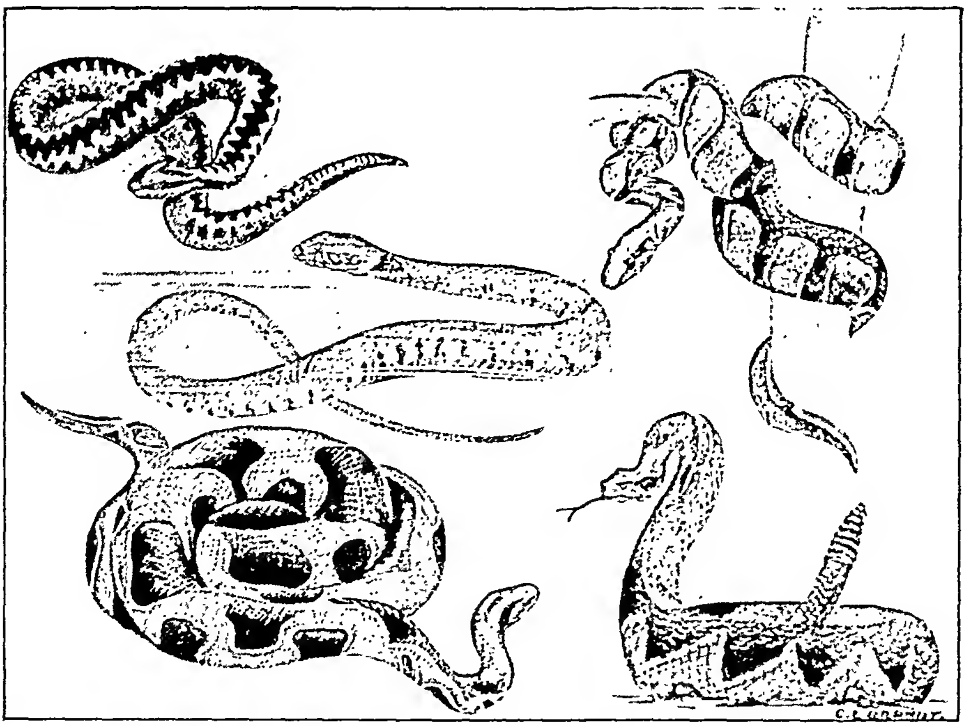


Fig. 17. Some of the better-known snakes: viper (top, left); grass-snake (centre); python (top, right); boa-constrictor (bottom, left); rattlesnake (bottom, right).

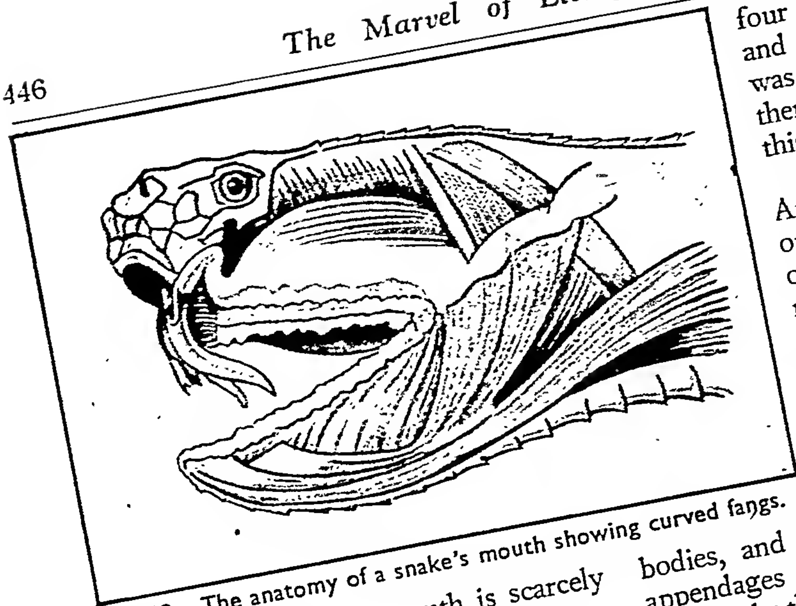


Fig. 18. The anatomy of a snake's mouth showing curved fangs.

the lips and that the mouth is scarcely opened at all.

The dangerous snakes inflict their poison in a bite. The large fangs fold back along the mouth to drop down when the mouth is opened and the snake raises itself to strike (Fig. 18). These fangs are grooved, and when the snake strikes and bites its victim, it presses on the poison sac at the base of the fang, which is actually the lachrymal or salivary gland modified. This squeezes the poison down the groove and into the wound of the victim.

The king cobra, or hamadryad, of Malay—10 ft. in length—is one of the largest and most poisonous of snakes. It rivals Russell's Viper of India for the latter honour, and it has the unenviable reputation of seldom hesitating to attack. Normally, it feeds on other snakes, and at the Zoo its fortnightly meals consist of snakes that cost £3 each! The first king cobra at the Zoo was placed overnight in a cage with four common cobras, and next morning it was found to have eaten them all—the cost of this meal was £12!

The puff-adder of Africa is little less dangerous than Russell's Viper of India, and the bushmen use its poison on their arrows.

The dreaded rattlesnakes (Fig. 17) of the New World are also vipers with broad triangular heads, short thick bodies, and the famous jointed horny appendages to their tails. In the baby rattlesnake this rattle resembles a terminal button, the various hollow, horny rings, which may attain twenty or more in number, being produced between this and the scaly tail. These rings consist of a quill-like substance, and are interlocked, and yet elastic enough to allow a considerable amount of motion betweer them and so to produce the curiou rattling noise, from which the repti derives its name. The purpose of t'

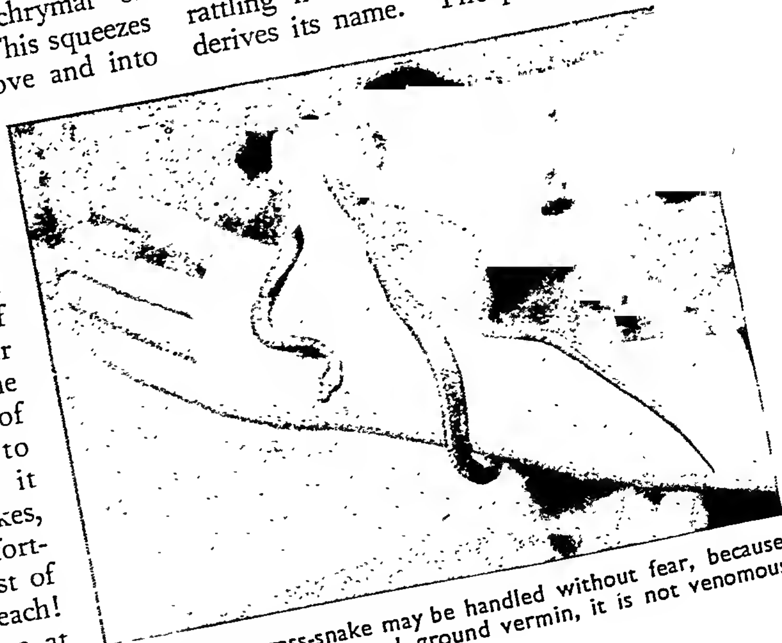


Fig. 19. The grass-snake may be handled without fear, because, though a killer of rats and ground vermin, it is not venomous.

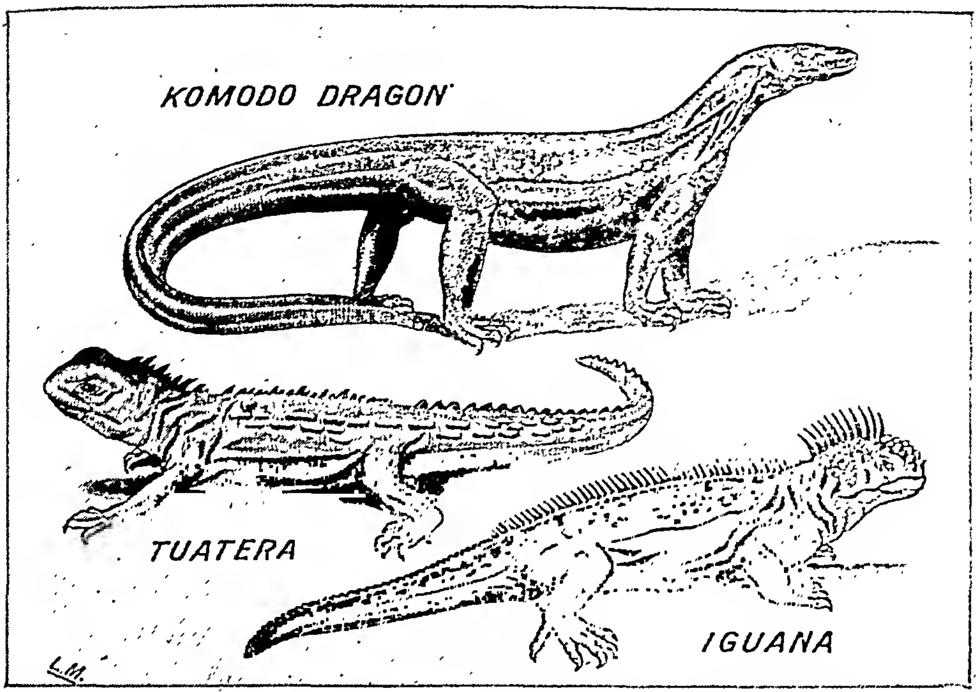


Fig. 20. Three remarkable remains of the Triassic Age. The Tuatera lizard comes from New Zealand. The komodo dragon from the East Indies and the Iguana lizard from the Galapagos.

rattle is believed to be similar to the appearance of the hood or frill of the cobra which is swollen before it attacks. These features serve the same purpose as the hissing of most snakes, that is, to terrorise victims into submission. Rattle-snakes, of course, do not hiss.

WHY SNAKES ARE VALUABLE

It is an erroneous idea that snakes are useless and dangerous creatures, for only a minority are poisonous. That they are valuable in their own sphere is evident from the fact that the recent trade in snake skins for shoes and hand-bags has caused strong protests from the tropics against the extermination of valuable species that destroy rats, mice, and other vermin. Even our British grass-snake, which is not venomous, is a useful killer of rats, field-mice, and ground vermin (Fig. 19). Recent research at London and Rangoon Zoos has shown that when diluted, the venom of that most deadly snake, Russell's Viper of India, is effective in curing sufferers from haemophilia, that dread disease in which victims bleed to death through the blood failing to clot.

Although the vipers include some of the most deadly snakes, they also serve their purpose in the economy of Nature. Some years ago, when the Intendant of the Imperial Castle of Lazemburg in Lower Austria offered a bounty for all vipers killed in the neighbourhood, over 1,000 were slaughtered in a single year.

Experts pointed out the foolishness of this procedure, however, and to test their theory, one was dissected and was found to contain the remnants of over one hundred grasshoppers—a great menace to agriculture.

Most reptiles shed, or slough, their old skins periodically. This sloughing

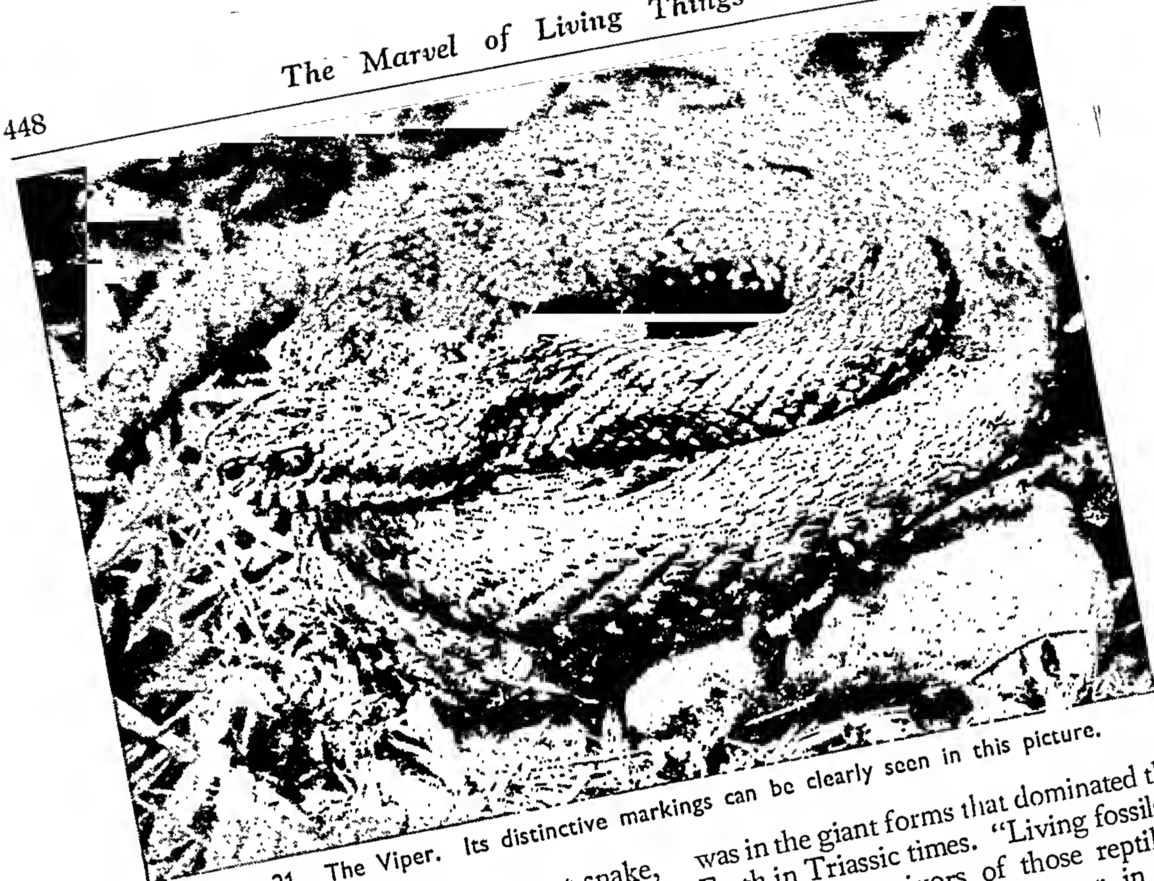


Fig. 21. The Viper. Its distinctive markings can be clearly seen in this picture.

is a good sign of health in a pet snake, for if not healthy it will have great difficulty in sloughing its skin. Normally this is rubbed off backwards, taking with it a complete transparent horny covering of the scales and even of the eye.

Practically all reptiles lay eggs in soft, leathery shells, and these are hatched by natural heat. Sand-lizards and turtles bury their eggs in the sun-baked sands. Similarly, in temperate climes adders bury them in manure heaps where warmth is generated. A few reptiles, including the common lizard, are viviparous, and either give birth to their young alive or they hatch from eggs a few minutes after laying. Despite an old tradition that in time of danger baby adders flee down the throats of their parents to emerge later when the danger is past, a handsome reward offered for proof of this happening has never been claimed.

The highest development of reptiles was in the giant forms that dominated the Earth in Triassic times. "Living fossils", or isolated survivors of those reptilian giants of the past, still linger in the world to-day. They are to be seen in the giant marine iguana lizards of the Galapagos Islands off Ecuador, the giant komodo dragons of the East Indies—already mentioned—and the curious tuatera lizard of New Zealand with its vestige of a third eye (Fig. 20). These ancient forms survive only because they inhabit land that has been isolated so long that more successful creatures, whose ancestors exterminated their relatives of the past, have been unable to reach their haunts.

IS THERE A SEA SERPENT?

We often see references to sea-snakes and sea-serpents from irresponsible sources, whose originators do not seem familiar with even those common objects of marine biology they try to identify.

There are true sea-snakes that are recognised by science, however, but these are quite different from the oceanic "monsters" so often described—the results in most cases of imagination.

The true sea-snakes, a sub-family of the *Colubrines*, inhabit the coastal waters of India, North Australia, and other tropical countries. They range from the Persian Gulf to New Guinea and are strictly air-breathing reptiles that come ashore to lay their eggs. They are highly venomous and are dreaded by the pearl-divers and by the fishermen in whose nets they may be caught. Their tails are usually flattened and oar-like to aid their swimming. Some are viviparous—that is to say, they produce living young—and many are brilliantly coloured. They feed on fish and other creatures they can capture, and have been seen hunting the shoals in the Bay of Bengal. The black-banded sea-snake is one of the most abundant found in Indian seas, and grows to a length of from one to six feet.

COMMON BRITISH REPTILES

Reptiles in Britain are confined to half-a-dozen, three of which are snakes. One of the best known is the big greenish-grey grass-snake, or ringed snake, with a yellow and white neck-ring (Figs. 17 and 19). It measures from two to three feet in length and although it has teeth in its upper jaw it is harmless. It gives out a foul odour when handled. A water-loving creature and rare in the North, it can swim well and haunts damp spots. The rare smooth snake of the New Forest and the South, some two feet in length, is a harmless creature whose scales are not keeled as are those of our other snakes. Our only poisonous snake, the adder or viper (Figs. 17 and 21) is a stumpy greyish-brown serpent about 10 in. in length, with a zig-zag yellowish line down the back that forms a V on the head. It has twenty-one rows of scales on its back instead of nineteen like the grass and smooth snakes, and is a creature of much drier habits than the grass snake, being found generally in the northern heathlands.

A SNAKE-FREE COUNTRY

It is a mystery why there should be no snakes in Ireland, although this fact is in keeping with the legendary curse placed on them by St. Patrick. The absence of many other common British animals, and the lingering of a great race of giant fallow deer there, is probably due to the land being isolated from the European mainland much earlier than Britain.

Snakes are by no means immune from foes. In Britain the hedgehog is an inveterate enemy of the adder, which it quickly kills by nipping it behind the head to break its backbone. In Egypt the mongoose—a little, ferret-like mammal—is a great snake-killer. The long-legged stork, the swallow-tailed kite, and other birds-of-prey also take heavy toll of the snakes.

Among our reptiles are three lizards. The common viviparous, brownish-yellow lizard is the smallest, the female being only 7 in. in length, and the male 5 or 6 in. Others are the egg-laying greyish sand-lizard, about 9 in. in length, and the big green lizard of the Channel Islands, 15 or 16 in. in length, which when kept as a pet sometimes has escaped into our countryside.

The blind-worm or slow-worm (Fig. 22) is very much mis-named. Although its appearance is that of a big, dark-brown worm with a bright eye, it is neither blind nor slow, nor is it even a worm. Actually, it is a leg-less lizard, the name having originated in sla-worm or worm-slayer.

Some of the other lizards—such as the

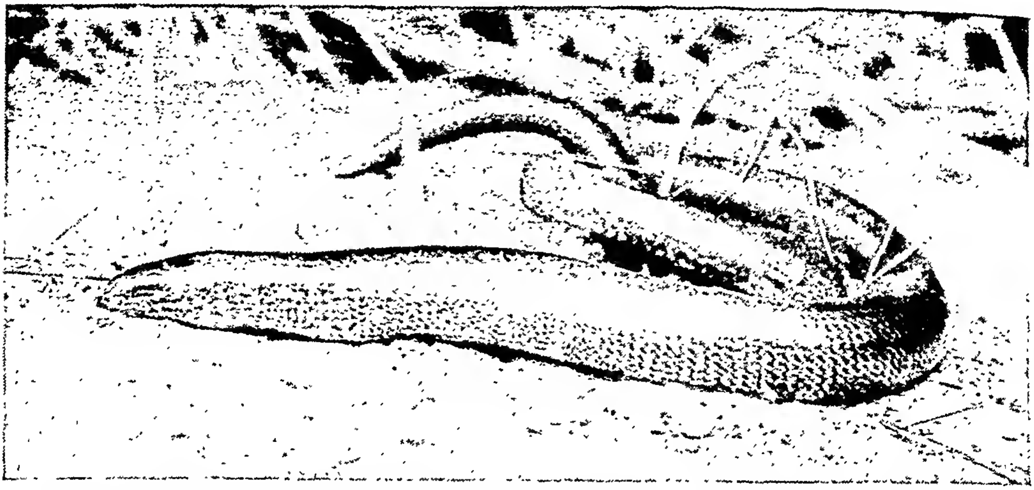


Fig. 22. The Slow-worm or Blind-worm is trebly misnamed. It is neither slow nor blind, nor yet is it a worm. Actually it is a legless lizard. The name was originally sla-worm.

ingenious insect-eating chameleon with a long tongue that it can flash out suddenly to catch some distant insect (see Fig. 23 page 451)—have the wonderful power of changing the colour of their skins. They do this in order to harmonise with their surroundings, or to express their feelings. The change is accomplished by contracting or expanding pigment cells. Although this habit is also possessed by some of the frogs, it is not an attribute of the snakes.

The chameleon has the very remarkable faculty of being able to direct one eye forwards and the other backwards, thus seeing both ways at the same time—a most valuable attribute.

THE ONLY POISONOUS LIZARD

Only one lizard is poisonous. This is the Arizona *Heloderma* or Gila monster, the poison of which is situated in glands near the roots of the teeth. This is a bulky, two-foot long pink-and-black reptile with a broad, stumpy tail. It makes sure of the effect of its poison by hanging on to its victim with a bulldog-like grip. Nature has enabled the *Heloderma* to store a food-reserve of fat in its tail—in which it is similar to the fat-tailed sheep—as a precaution against times of scarcity.

The most famous lizards of to-day are the giant Komodo "dragons" of the Dutch East Indies. They grow to a length of 12 ft.

The little flying dragons of Malay have elaborate crests and wattles. The large expansion of their ribs, which bear gaily-coloured membranes, enables them to glide through the air from tree to tree. Even more marvellous are the frilled lizards of Australia. When excited they raise a coloured Elizabethan-like ruff nearly 10 in. in diameter. At the same time their jaws open wide to display a saffron-yellow mouth, the whole appearance being so awesome as to scare away any would-be enemy.

The diminutive horned-lizards of Mexico are gruesome specimens. Although only a few inches in length, the head and sides of the body bristle with long spines. When molested they squirt thin jets of blood from the corner of each eye; these jets travel as far as six feet.

The lobe-footed gecko belongs to a group of lizards inhabiting India and Australia, and is chiefly nocturnal in its habits. As in the case of the house-fly,

:s feet carry sticky cushions by which : is able to walk up walls and ceilings ɔ catch insects. Geckos generally ıhabit native houses in the tropics, ttering the shrill cries "*yecko*, *checko*," rom which they are named. The rilled or fringed gecko of Malay and the East Indies is a tree-dweller and can fly n a similar way to the flying dragon.

A LIZARD WITH HORNS

In the mountains of Ceylon there is he rare horned lizard, on the nose of he male of which are long horn-like growths, ½ in. in length.

In Java and the Philippines the sail-ail lizard has a sail-like crest along its ail, supported by a lengthening of the pines of the vertebrae of the tail. It s one of the few lizards found living in vater.

On the other hand, the thorny-tailed izard of North Africa has a tail with ings of spiny scales on its upper part, so that it cannot be picked up by the tail like most lizards. When this is done with the common lizard it usually sheds his tail, leaving a wriggling limb to engage your attention while the creature makes good his escape possibly to grow a new—but inferior—tail.

In the Tropics, there are some descendants of the ancient mighty reptiles. These range from the ancient tuatera or beaked lizard of New Zealand, and the wonderful axolotls—the "Peter Pans" of Nature—to the crocodiles and alligators. Let us consider briefly some of these marvellous and surprising reptiles.

The huge, sluggish, crocodiles and alligators (Fig. 24), which so forcibly recall the pictures of the giant saurians of the past, are not so closely related to the common lizards as their shape might lead us to suppose. Quadrangular, horny, shields form an armour on their backs, and their toes are more or less

Fig. 23. The chameleon, with its wonderful power of accommodating its colour to its surroundings, is another member of the lizard family. Chameleons live entirely on insects.

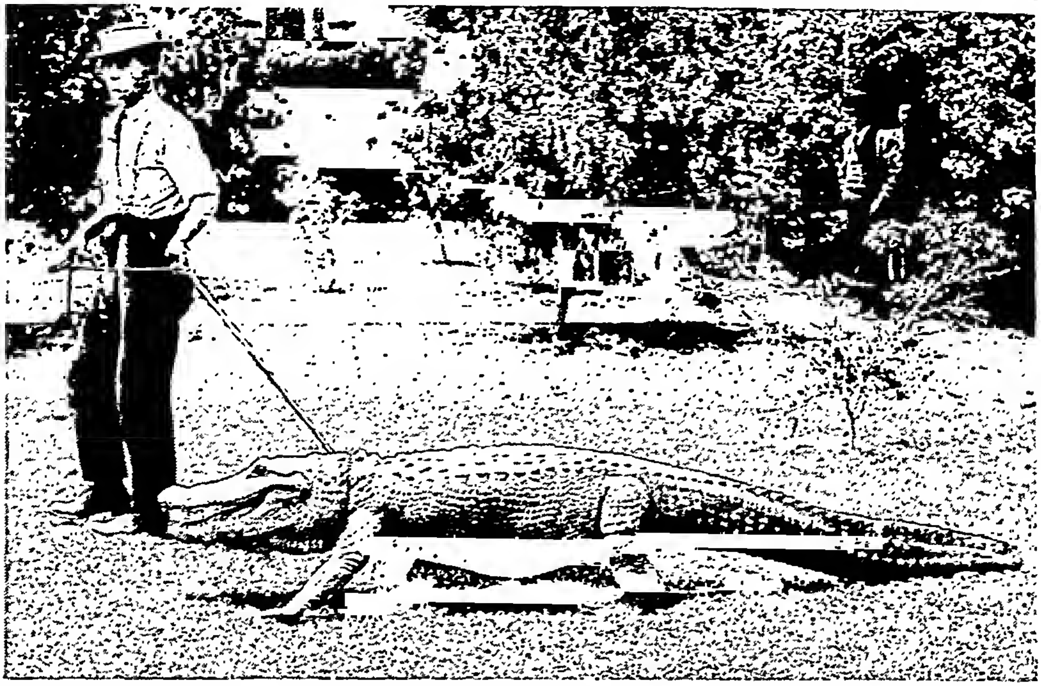


Fig. 24. There's no accounting for tastes! This beautiful specimen of an alligator is kept as a pet by a resident of Los Angeles, California. It is regularly taken for exercise on a lead by its attendant, and is a popular pet with all visitors. The American alligator attains a length of sixteen feet.

webbed. Their hearts differ from those of all other reptiles in having four chambers, indicating a high form of development and showing a very advanced state of evolution.

HOW THE CROCODILE BREATHES

Because its wind-pipe grows upwards to the nasal passage and has a bony intervention shielding it from the remainder of the mouth, a crocodile can lie on the surface and breathe air, although its mouth remains below the surface and is actually full of water. The eyes, too, are raised so that the creature can scan the water surface while remaining safely hidden from view below. Except for an Indian species found floating some distance from land, these creatures are usually found in the world's greatest rivers and in their estuaries.

In South America there are the caiman crocodiles of the Amazon and Orinoco; in West Africa the long-nosed crocodile; and in the Ganges the curious garial, which has a long and slender snout with curved slender teeth, like the Ganges dolphin: These last creatures, the one a reptile and the other a mammal, feed on the same kind of food under similar conditions, giving us another indication of evolution working in relation to environment and the necessity for obtaining food.

Crocodiles are excellent swimmers, but very awkward on land, for which reason they seldom wander far from water. All are carnivorous and largely nocturnal in their habits, feeding on fish and small game. Because their gullet is so small, they are compelled to mangle and rip up their prey before swallowing.

Crocodiles and alligators lay from twenty to sixty white, goose-like eggs (Fig. 25). Having buried these in the sand, the female leaves them to hatch, sleeping on the summit of the nest above.

When the young are ready to hatch they cry in a way similar to that of a baby bird that can be heard crying before the eggs hatch. Then the parent digs down to allow them a free passage through the sand, and the young crocodile perforates the shell. (Fig. 26). It does this by the aid of a specially developed tooth, similar to the "egg-tooth" developed on a chick in the shell. A crocodile's egg takes about ninety days to hatch, and the young crocodiles grow at the rate of about 1 in. a year. Thus a 2 ft. crocodile is about fifteen years old, and a 16 ft. crocodile is a centenarian.

The sacred mugger crocodile in the pool at Manghophur, near Karachi, is reputed to be over 100 years old. He is so old that he has lost most of his teeth, and is too feeble to fight for his food. He has to be fed artificially.

CLASSIFICATION OF REPTILES

In the classification of reptiles, the crocodiles are placed just ahead of the extinct Dinosaurs, as represented by the Iguanodon and the flying reptiles or Pterodactyls. They are followed by the tortoises and turtles, and then by other extinct reptiles, the giant Plesiosaurs.

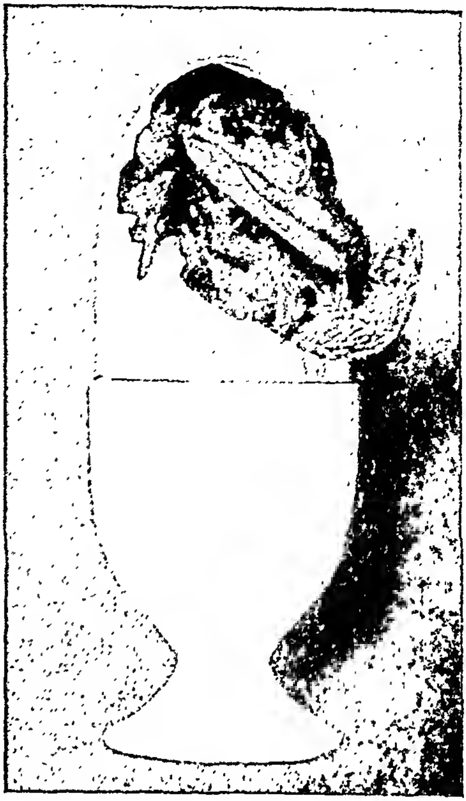


Fig. 26. An alligator breaking out of its egg.

So far as tortoises and turtles are concerned we should correct the common belief that "tortoise-shell" has something

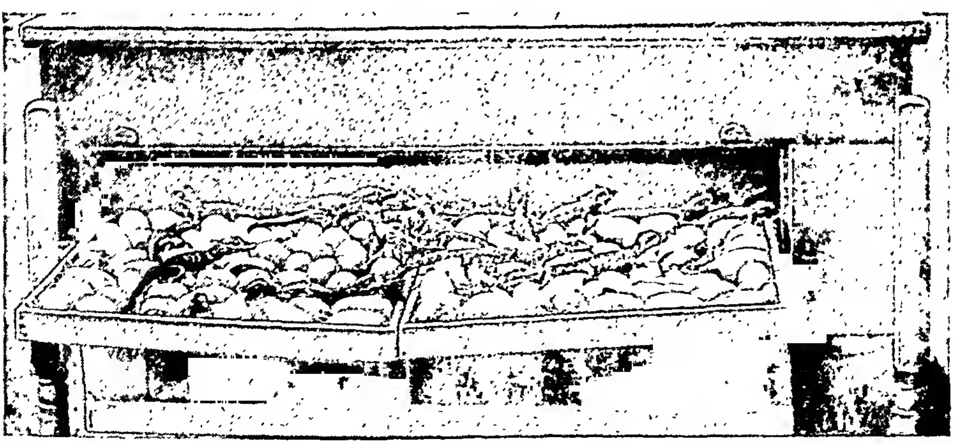


Fig. 25. Alligator eggs hatching out from the incubator on an alligator farm. They are reared for the sake of their valuable skin that is made into handbags, and similar articles.

to do with tortoises. It is obtained from the hawksbill turtle, a creature that has no other human uses, not even being suitable for soup, as is the green turtle. The beautifully mottled plates of its horny "shell", or carapace, take a high polish and are used for many purposes. At one time the shell was obtained by steaming the animal until the plates came away, when the creature was released to grow a second, but, compared to the first, vastly inferior set.

THE TORTOISE'S DIET

Another fallacy is that the common Greek tortoise, sold as a garden pet, will devour great numbers of garden slugs and kitchen cockroaches. It is one of the vegetarian reptiles and certainly will devour lettuces and greens, as you may prove by allowing it free access to the kitchen garden. A hedgehog is more useful as a pest-destroyer.

All chelonians, as tortoises and turtles are scientifically called, have a more or less fully developed bony shell or carapace. Their skulls resemble those of the crocodiles more than those of any other group of reptiles.

The largest of all the tortoises is the Atlas Tortoise of the Siwalik Hills of Northern India. It reaches a length of 6 ft. and as in the case of the giant tortoises from the Seychelles and Galapagos Islands, is believed to live for over a century—sometimes for perhaps 200 or 300 years. The carnivorous water tortoises, or terrapins, have flatter shells. The curious big-headed tortoise of South China, Siam, and Burma, is a most grotesque creature, that looks exactly as if it had been run over causing its shell to be flattened; its head bulges to enormous size.

Another curiosity is the matamata tortoise of Brazil. It belongs to a group called the side-necked tortoise, and instead of having the usual horny, parrot-like beak, it has a nose that is a curious proboscis. Its neck is frilled with little fimbriated projections, and the horny shields of its carapace stand up like tiny mountains on a relief map. The snake-necked tortoise of the same country is named from its habit of withdrawing its head into its shell by placing it sideways instead of following the S curve of the other tortoises.

Turtles differ from water-tortoises in having their limbs developed into swimming paddles, and they rarely come ashore except to lay their eggs.

Finally, at the bottom of this group are the amphibians or batrachians—the frogs, toads, newts and salamanders. At one time these creatures were included with the reptiles, but they are now classed apart. Their chief difference is the metamorphosis in their life-histories from an aquatic egg—and fish-like larval form—of which the frog's spawn and tadpoles are familiar examples—to a terrestrial adult stage. They also have a soft, naked, skin quite unlike that of the true reptiles.

The life history of the common frog is typical of that of any amphibian, although there are some tree-frogs (living in an island of the Leeward group) the eggs of which hatch on the damp forest floor direct into the adult frog without any tadpole stage. Actually, this stage is rushed through inside the egg, for these frogs dwell in the trees, their only water—swift mountain streams, for there are no forest pools there—being unsuitable for breeding, hence this fascinating adaptative trend of evolution.

HOW FROGS PROTECT THEIR EGGS

In the case of our own frogs, the spawn (Fig. 27) is laid in the ponds and brooks in March and the gelatinous cover swells into large jelly like balls. These are distasteful to fish and thus protect the eggs from would-be

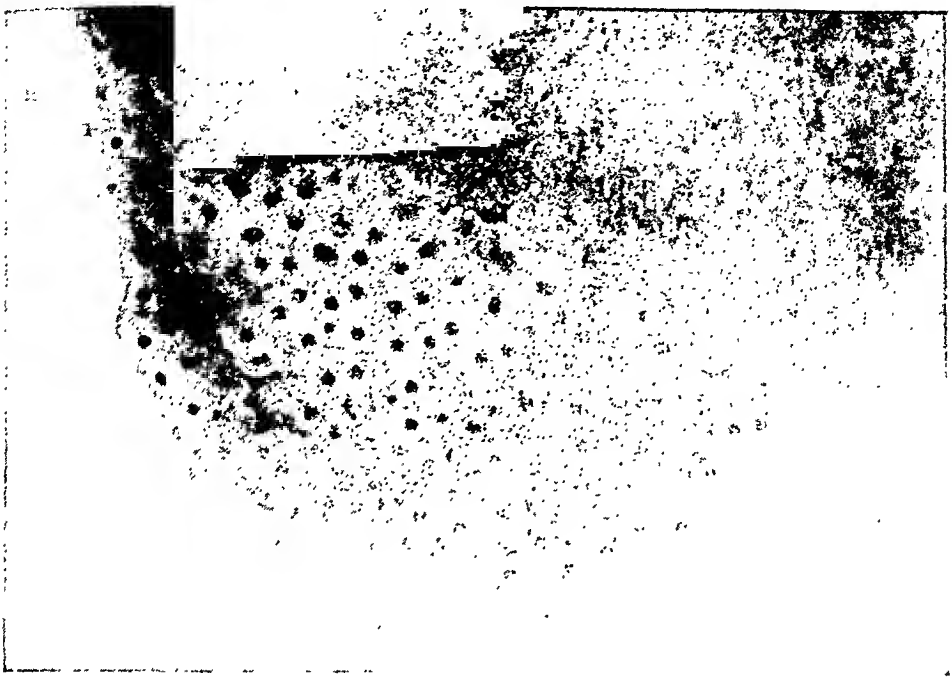


Fig. 27. Jelly-like frog-spawn. The black dot in the centre of each jelly cell is an embryo.

enemies. The young tadpole, hatching from the black embryo of the egg—clearly seen in the photograph in Fig. 27—by a series of divisions of the cell as it grows, feeds on the jelly. It develops a head and tail and a suctorial mouth until, having absorbed all the jelly, it clings by that mouth to the pond weeds. Here in masses it feeds on the vegetation—if it is not devoured by dragon-fly larvae, water-beetles, or other foes.

Gradually, hind legs develop in the little tadpole, which swims by wriggling its tail. Then the frill-like pair of external gills, which were on each side of the neck, wane, internal gills having meantime been formed. These have a gill-plate, or *operculum*, covering them just as we saw was the case in the fishes, for the tadpole is to all intents and purposes a little fish without side fins. Then the tail shortens and loses its fin, the front legs push through the gill-plates that have hidden their early growth, and the little frog becomes terrestrial. This metamorphosis takes about three months. It is now autumn and the frog will spend the winter hibernating in rock-holes, returning to the water the following spring, although frogs do not spawn until they reach about the age of two or thereabouts.

HOW FROGS BREATHE

The adult frog can live in water, of course, but it spends most of its time in the nearby damp vegetation. If we look at a frog we see how it has three methods of respiration or breathing. Its throat seems to be constantly pulsating, but actually this is the floor of the mouth pumping air in and out of the nostrils, for the moist lining of the mouth is covered with blood vessels and acts as the main means of respiration. Occasionally the frog takes a deeper breath and uses its lungs. The third method of respiration is by means of its moist skin.

Thus it is that an adult frog kept in a tank of water must come to the surface to gulp in air to breathe. Without a rest-place, such as a stone or floating cork, it will ultimately drown.

SPECIES OF FROG

Our common British frog has black temples and unspotted thighs, as well as the ability to vary its greenish-brown colour lighter or darker to suit its surroundings. There is in addition the edible frog, a larger, greener frog, with grey temples and spotted thighs.

Sometimes we read accounts of "migrations" of frogs when they are met with in enormous numbers crossing roads. These are usually the normal spring movements from winter quarters back to the ponds for spawning, and at such times vast numbers of frogs congregate in some favourite pond. Some of the most vocal of all frogs at these gatherings are the North American bull frogs; some of the most beautiful are the bright-green tree frogs that harmonise with the foliage where they climb in pursuit of insects; amongst the most gruesome is the Argentine horned frog. In Java there is a flying frog with toes and webs so enormously developed that they act as parachutes when the frog leaps great distances from tree to tree. In the Solomon Islands there is the sharp-nosed frog, the nose of which comes to a sharp

Fig. 28. The newts are a group of tailed amphibians closely resembling frogs in m... ...cteristics, but they do not lose their tails nor do they have such large hind legs. ...ls instead of their legs, and their tadpoles have more colour than th...

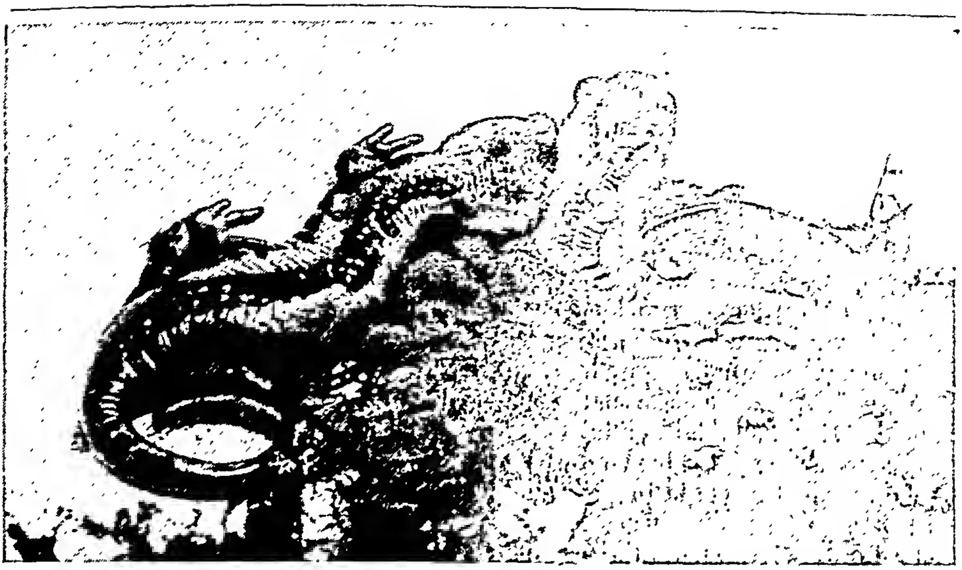


Fig. 29. These repulsive little animals are salamanders. They are often kept as pets for they thrive well in fairly dry conditions. One species of salamander—the Mexican Axolotls—rarely reach maturity, retaining their external gills right through life.

point. In South America are the piping frogs, so named from their loud, piping croaks.

Frogs are great insect-eaters and take toll of a large number of injurious insects. Their long, flexible tongues, rooted at the front of the mouth, fold back so that when flicked out rapidly they have a double extension enabling them to catch many a moving insect outside the frog's normal range.

MALE FROG AS INCUBATOR

Most of the frogs and toads puff out their bodies when alarmed, but the short-headed frogs of East Africa inflate to an enormous degree until they closely resemble india rubber tennis balls. In Darwin's frog of Chili, the throat sacs of the male are enlarged and modified to form an extensive chamber on the under surface of the body. Here the eggs and tadpoles undergo their development free from any danger or attack from their enemies.

The main difference between frogs and toads is that the latter have a warty instead of a smooth skin, no teeth, and less webbing on the toes. Toads are less agile and rarely if ever hop—they crawl. Their eggs, or spawn, are laid in double rows instead of masses. They, of course, cast their skin as they grow, as did their reptile ancestors, and the common toad often eats his cast skin.

It is a fallacy that toads are poisonous, but their skin has an acrid taste that usually forces dogs to drop them once they are seized.

The most remarkable of all toads is the Surinam water-toad, one of the tongueless toads of Guiana and Brazil.

HATCHING THE EGGS

The female lays her eggs in the water, and at this time her soft back becomes much thickened. The male collects the eggs as soon as they are laid and embeds them one by one in the soft skin of the female's back. This soon closes over so that each egg is protected in a separate cell, from which a young tadpole emerges 82 days later.

The female may have as many as 120 such cells in her back, but 50 or 60 is the average. After the birth of her family, she rubs off the surplus skin from her back against plants and stones.

THE MIDWIFE TOAD

The midwife toad or frog of Central Europe, belongs to the disc-tongued frogs. It lays its eggs in long chains from March to August. These chains, which may be a yard or more in length, are gathered by the male and wound round his legs and thighs until he is too loaded to move. He then retreats to some burrow or hole in the bank until the tadpoles are ready to hatch, when he returns to the water, the tadpoles swimming away to take care of themselves.

The newts (Fig. 28) and salamanders (Fig. 29) are a group of tailed amphibians very much like frogs. They do not lose their tails, however, nor do they have such large hind legs. They swim with their tails instead of their legs and their tadpoles usually have more colour than those of the frogs and toads.

The orange crest of the newt is part of its spring courtship display. The great warty, or crested, newt has a high and serrated crest starting as a collar-like fold of skin round the throat and stretching down the back and over the tail.

In most of the newts the female is the larger of the sexes and more orange in colour. The metamorphosis of the newts is often less complete than that of the frogs, and some of their allies even retain gills in the adult state, although this is not so with the salamanders. These belong to a very large group closely related to the newts and are often kept as pets, for they tolerate drier conditions than a newt can.

The most remarkable of all this group of amphibians are the Mexican axolotls. Unless they are fed with a special thyroid gland extract or have their water supply reduced, they do not normally complete their full metamorphosis to adult stage. They retain their external gills and aquatic habits, breeding thus and producing more axolotls. For this they are very popular pets with the aquarists. The axolotl is thus usually in a permanent larval form. The majority of its relatives pass from the tadpole to the salamander stage in the ordinary way, although on the rare occasions when it does reach that stage, the adult form resembles a large-headed salamander, with short, stout limbs and a broad blunt muzzle, and a shining dark brown skin spotted yellow.

THE GILLED SALAMANDER

Some of the other salamanders are eel-like in their long bodies with tiny three-toed limbs. The famous blind olm, or Proteus, is a gilled salamander that lives in the subterranean waters of Dalmatia. It has a 10-in., eel-like body with four tiny limbs. Through long lack of use in those dark waters, its eyes are covered over by skin so that it is totally blind.

Finally, in Ceylon, India and Java there is the curious worm-like salamander called *Coecilia*. This is a slender, 15-in. worm-like amphibian that burrows in the soft mud, laying a cluster of large white eggs around which the female coils herself and broods them as a python broods its eggs.

CHAPTER 19

INSECTS AND OTHER LOWLY CREATURES

ALTHOUGH Man, at the head of the great backboned, or vertebrate, group of animals has almost conquered the world, his chief rivals are the tiny insects. They take about one-tenth of his crops annually, and cause damage to goods and merchandise to the value of millions sterling. This damage ranges from the ravages of the termite in the tropics to the fruit-flies in the New World, and the disease-carrying house-fly in Europe and elsewhere.

In considering insect life we explore the great and wonderful world of little things in Nature. Here we deal with the invertebrates, or backboneless animals—or, as they are better called, those without a spinal cord.

The invertebrate world is divided into six main classes. These are (1) the *Insects*, known by the three pairs of legs growing out of the chest or thorax; (2) the *Molluscs* or "shell-fish"; (3) the *Crustaceans*, such as the crabs and lobsters; (4) the *Radiate-Designed animals*, like the sea-urchins; (5) the great group of worms or *vermes* that form a kind of dumping ground at the bottom of the classification. This class contains our common earthworms and many other lowly creatures, such as the rotifiers, or wheel-animalcules so fascinating under a microscope. Finally, there are (6) the simplest of all the animals, the single-celled *Protozoa*. From these latter creatures, life began on Earth, and their method of growth and reproduction by cell-division still remains the basic method common to all the higher animals.

Now, why should an insect not have bones, and why should it instead have a hard outer skin? It seems evident that these lowly, backbone-less creatures were developed by Nature before she had experimented with the higher forms. In her efforts to protect them from the various dangers of life—especially at a time when soft-bodied aquatic creatures had taken to life on land—she evolved the hard, chitinous external skeleton in which all the soft parts were contained.

We might think that this form of construction may not be so good as the

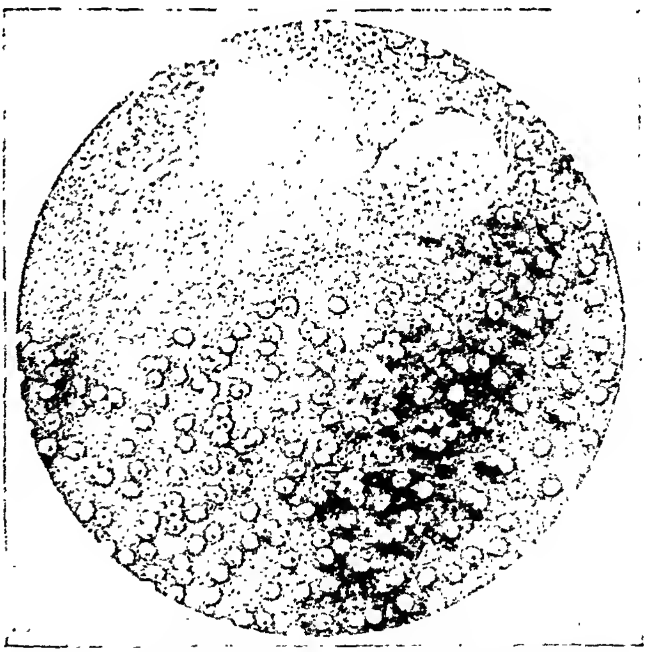


Fig. 1. Cocoon and eggs of the Garden Spider (*Epeira diadémata*).

Fig. 2. Young garden spiders hatching out from the eggs shown in the cocoon in Fig. 1.

internal skeleton, whereon the muscles of the higher animals are placed. One disadvantage might be supposed to be that the hard case of the adult does not expand to allow the insect to grow, and for this reason all its growing has to be done in the earlier stages of its metamorphosis—when it exists as a maggot or grub. If the hard skin is cracked or broken, it usually means the end of the insect. But an external skeleton is far simpler to form than the skeleton of the vertebrate, and such lowly animals could not manufacture so complicated a structure as the human skeleton.

So different are the invertebrates from the vertebrates that we find an endless list of mysteries as soon as we begin to examine the subject. Spiders may be confused with insects, and cockroaches with black beetles; but the spider is very different from an insect and a cockroach is not a beetle. True insects have six legs and wonderful compound eyes, composed of a mosaic of a thousand or more tiny lenses (see Fig. 5). Each sees a separate portion of the view and builds it up into a picture, as the stones of a mosaic build up their picture. They have a remarkable breathing system. The body is honey-combed with little air-tubes, or *trachea*, and there are breathing-pores in the sides of the insect. Its body-movements pump in air, and work it round the body in place of our system of blood-circulation. The reason why we sprinkle insect-powders on the kitchen floor is that they clog up the breathing-pores of the pests and kill them by suffocation.

REPRODUCTION OF GREEN-FLY

A spider has eight legs, while it breathes by means of two little air-sacs, or "lung-books". Its eggs hatch into small replicas of the adult spider (Figs. 1 and 2), whereas the young of most insects hatch out as grubs (Fig. 3).

The beetles make up a group of insects that includes the dor-beetle, the cockchafer, the ladybird, the devil's coach-horse and the great stag and antler-beetles. All are identified by their having two pairs of wings, one soft and for flight, and the other hard and chitinous, to fit over and protect the flight wings (Fig. 4). The hard wings are called the *elytra*, and although the male cockroach has flight-wings he has no elytra and is therefore not a true beetle. In point of fact, the cockroach belongs to the *Orthoptera*, a group that includes the locusts, grasshoppers, ear-

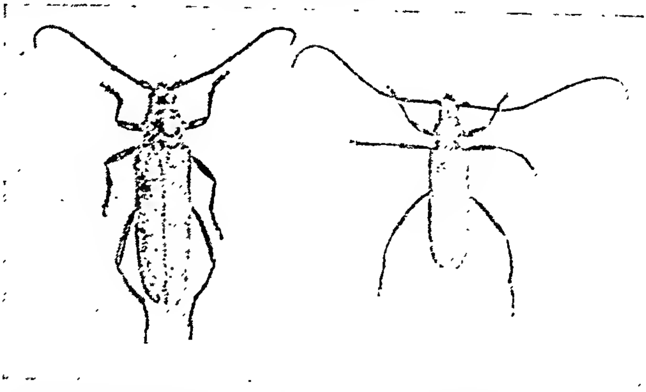


Fig. 4. Beetles have two pairs of wings. Here the elytra (or hard outer wings) are seen fitting over the flight wings for protection.

wigs, and the ferocious praying-mantis of the tropics.

Even more remarkable than the ability of the *amœba* to live for ever by simply dividing into two, is the wonderful method of reproduction of the *aphides* or greenfly, and of some other of the lowly animal forms. This method is called parthenogenisis, a word meaning reproduction without concourse of sexes or union of sexual elements. As we have seen, in the simplest single-celled animals like amœba, reproduction is merely a division into two. In these creatures, a little higher in the scale, it may be accomplished by a budding off, as with the tapeworm. Higher and more complicated animals develop two different sexes, male and female. Some, like the Hydra, a fresh-water polyp relative of the sea anemone, have both a sexual

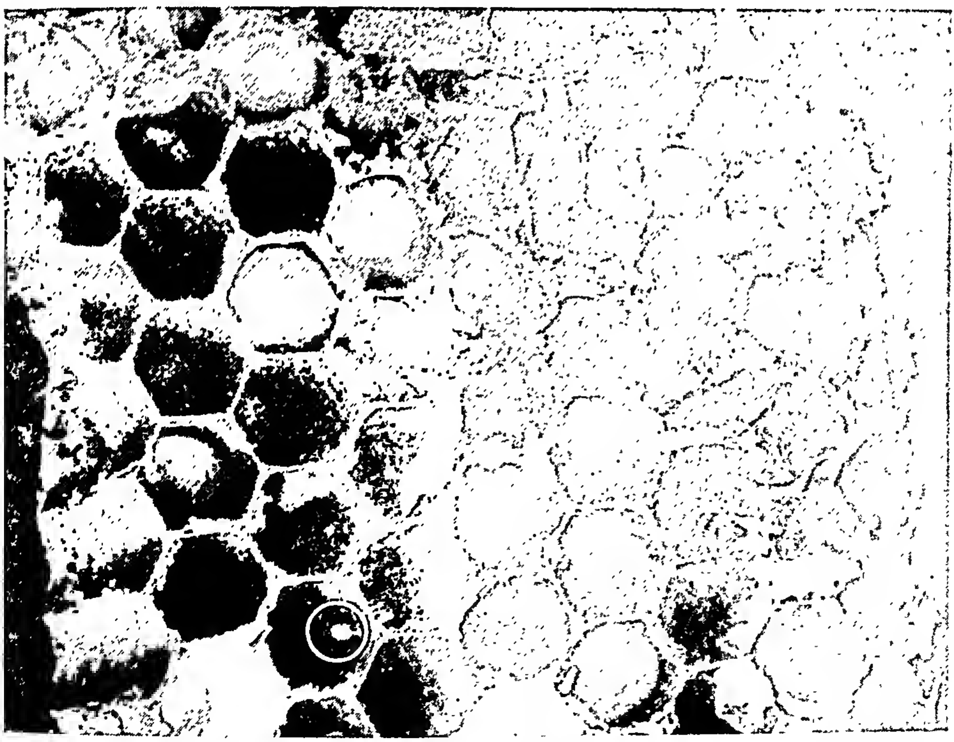


Fig. 3. The small white object in the cell in the bottom left is a wasp's egg. This will later hatch into a grub, as seen in other cells. Later still these grubs become perfect insects.

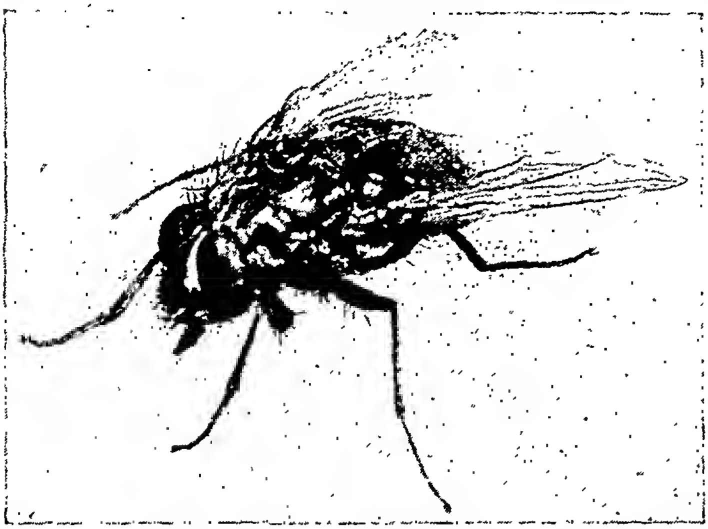


Fig. 5. The common house-fly. Flies have two pairs of wings and compound eyes, composed of a mosaic of lenses. Notice the hairs that carry the disease germs.

budding and sexual reproduction. Others, like the earthworm, are hermaphrodite—that is, with both male (sperm-producing) and female (egg-producing) organs in the one animal. In such a case, however, in order to keep a virile stock, two different worms usually mate, the sperm from one passing into little pockets on the back of the other. Worms act as males one season, and females the next. The noticeable collar, or *clitellum*, formed around the body of a worm is really the egg-girdle, resulting from such mating. It is finally passed over the head when ripe.

With higher animals the two separate sexes must unite in fertilisation before reproduction can take place. The splitting, or halving, of the chromosomes (the heredity qualities) in the cell-nucleus to produce the two sorts of germ cells, male and female, makes this fusion necessary. Otherwise, the number of chromosomes required to

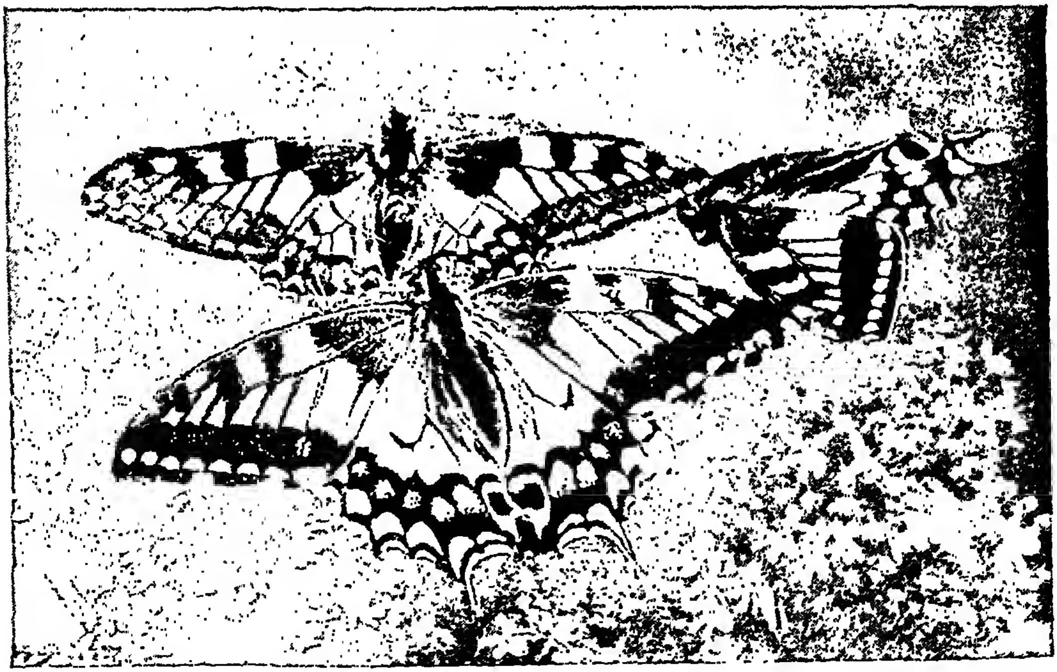


Fig. 6. Butterflies and moths both have two pairs of flight wings. Above we see three magnificent examples of the British Swallow-tail Butterfly, a most beautiful specimen.

Fig. 7. Emperor Moth showing "eye-spots".

build up a replica of the species in its offspring would not be available. Among the *aphides*, however, the females can go on reproducing generation after generation of offspring without coming into contact with a male aphis. In some rotifiers, or wheel-animalcules, members of the *Vermes* or worm-group, the male has never been found, yet the fertility of the female is very great. Male *Daphniae*, or water-fleas, often die off in a collection and are unrepresented for long periods. Male aphides may be absent from a colony all summer without affecting the breeding properties of the females. In other words, these eggs develop without being fertilized, but structurally they are slightly different from normal eggs.

We should here mention that many creatures are misnamed, as for instance the glow-worm. If we look at the glow-worm, which shines in the damp hedgerows of an autumn night, we see it is not a worm, but an insect. It has six legs, while the male is equipped with wings and is a beetle.

We may ask: "Is the butterfly really a fly?" Actually it is not a true fly, for the true flies, or *Diptera*—such as the house-fly and gnat—have but two flight-wings (Fig. 5). The other pair have degenerated into two tiny knob-like balancing organs, or "halteres", on the thorax. On the other hand, the butterflies and the moths have four flight-wings (Fig. 6) and these are covered with microscopic scales in a most intricate pattern (Figs. 7, 8, and 9). Some of these scales are coloured whilst others reflect the light. For this reason, these insects are called the *Lepidoptera*, or scaly-winged insects.

Neither the bees nor the wasps are

Fig. 8. Part of the wing of the Emperor Moth showing the "eye-spot" in detail. Note the scales lying in a series of layers.

included in the group of *Diptera* or flies. They have four wings (Fig. 10), but these are not covered with scales. As in the case of the ants and saw-flies, they, too, have a very slender waist joining the abdomen and the thorax. For this reason these insects are called the *Hymenoptera*, or slender-bodied insects.

The dragon-flies, may-flies, alder-flies, caddis-flies, and their allies with four wings, are in another group, called the *Neuroptera*, or nerve-winged insects. They are so named because of the complicated nervures that mark their wings.

Many insects, such as flies and butterflies, lay eggs that hatch into grubs or caterpillars (Fig. 11). They feed and grow until they turn into mummy-like *pupae*, (Figs. 12 and 13), in which state they often pass the winter, hatching out later as perfect insects. The eggs of others, such as the cockroaches, hatch into "nymphs" or replicas of their parents. They are not quite complete, however, because they may lack wings, but these they subsequently grow by a series of moults of the skin until at length they attain the adult stage.

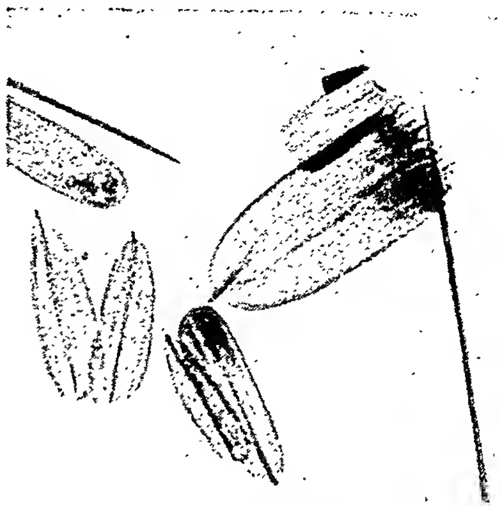


Fig. 9. Scales from the wing of a moth photographed through a microscope. They are not unlike a bird's feathers in construction, as can be clearly seen from this picture.

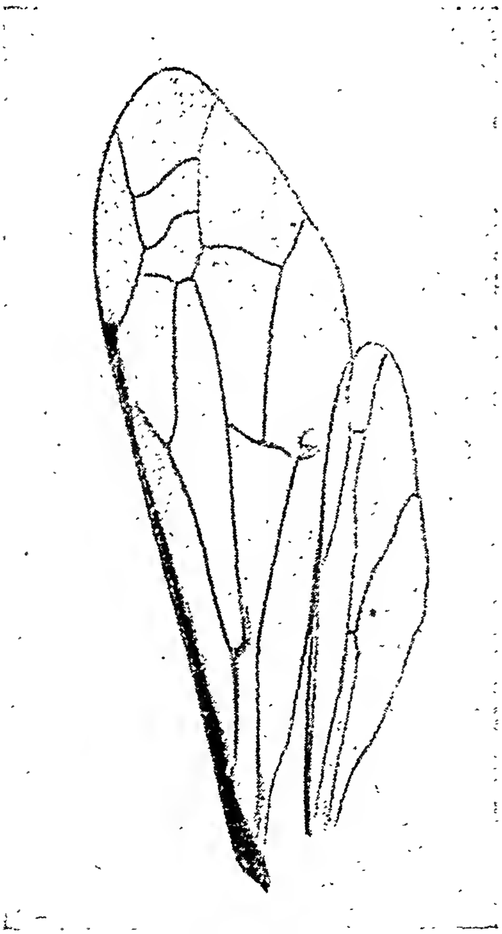


Fig. 10. Pair of wings from one side of a bee.

HATCHING OF INSECT EGGS

Now, why cannot the insect's egg hatch into the perfect adult form, as in the case of a bird or reptile egg? We have already seen that the insect is a much lower and simpler form of animal life, and its egg is not nearly as complicated, nor so well-developed, as the egg of the bird or the reptile. Nor does it carry anything like as much nutriment for the embryo within. Because of this simpler egg, the creature must first hatch out as the larva or grub or caterpillar, in which form it can obtain the energy to continue its development by feeding. When this is completed, it turns into the pupa and from this the

Fig. 11. Caterpillars of the Lappet Moth showing their size in comparison with that of a hand.

adult hatches. Thus, the metamorphosis of the insect-grub to the pupa is but a prolongation of a development that cannot take place in so simple an egg.

As we have already seen, it is easy to confuse some insects with others. On further examination, we find possibilities for even more confusion. There is, for instance, a bee-fly, that looks very much like a bee, and has similar yellowish bands. Yet its wings show us that it is not a bee but a true fly. Many other examples of mimicry might be mentioned (Fig. 14). As everyone knows, wasps and bees sting, and are thus dangerous to any bird or beast that tries to devour them.

So Nature gives the wasps and bees a warning colour—yellow—as she gives the warble and bot-flies a warning buzz. These protections are sufficient to cause young birds instinctively to avoid eating insects so coloured—as, for instance, in the case of the bitter black-and-yellow-banded caterpillar of the Cinnabar moth that so commonly feeds on the ragwort of the coastal fields. In the long story of evolution, however, a fly that was so

Fig. 12. The caterpillar of the Emperor Moth, beginning to make its cocoon. Inside this it turns into a mummy-like pupa to emerge later as a perfect moth. Details of the Emperor Moth's wing are shown on page 463.

Fig. 13. Chrysales of the Emperor Moth, wintering in flask-shaped cocoons. This photograph was taken against a strong light to show the pupæ inside the cocoons.

tempting to the birds, learned that by imitating the warning colour of the bees it might escape being eaten, for the birds mistook its harmless form for a bee.. Thus the bee-fly developed.

A LAMB IN WOLF'S CLOTHING

The ugly-looking caterpillar of the puss moth, often found on poplars and willows, rears up and protrudes its scarlet filaments from two horn-like appendages above its tail, when confronted. Here again is an example of Nature's bluff to save some of her tasty children from being eaten alive, for the puss-moth caterpillar is quite harmless, despite its ferocious appearance. We misjudge some of the useful insects, however, and the wasp, which has almost every hand raised against it, is a very useful and efficient destroyer of house-flies.

At the head of the invertebrate world, we have a great group of animals called the *Arthropoda*. This order includes the insects, crustaceans, and spiders, each of which has the body distinctively divided or jointed. At the head of the insects, of which some 400,000 species are known, are the ants, bees, and wasps. But we do not find the "White ant" or termite here. This terribly destructive tropical insect bores away the interior of furniture and woodwork, and builds vast underground colonies leading down to water. Its vast skyscraper-like "ant-hills" are raised 12 ft. above the ground. The termite is not a true ant, but an orthopterous insect related to the cockroaches, locusts, the mayfly and "book-lice" (Fig. 15). Once more we see how misleading are many popular names.

SOCIAL LIFE AMONG INSECTS

Yet it is amongst the ants, bees, and wasps—and to a lesser extent among the termites—that social life in the insect world reaches the peak of development. In the large bee-hives and ant-colonies there are usually three kinds of insects—a fertile female or queen; a number of neuters, being workers, or infertile females, and the males, or fighters. In summer when the young queen ants attain their wings and make a grand nuptial flight into the air—much like the flight of a queen bee with the drones swarming after her—the male ants fly up, too, and the strongest and swiftest flier mates with her. Then, the flight over, the queen ant bites off her wings and returns to her galleries below ground.

The biggest British ant, is the red wood ant (Fig. 16) that builds fairly large ant hills in the woods of the South.

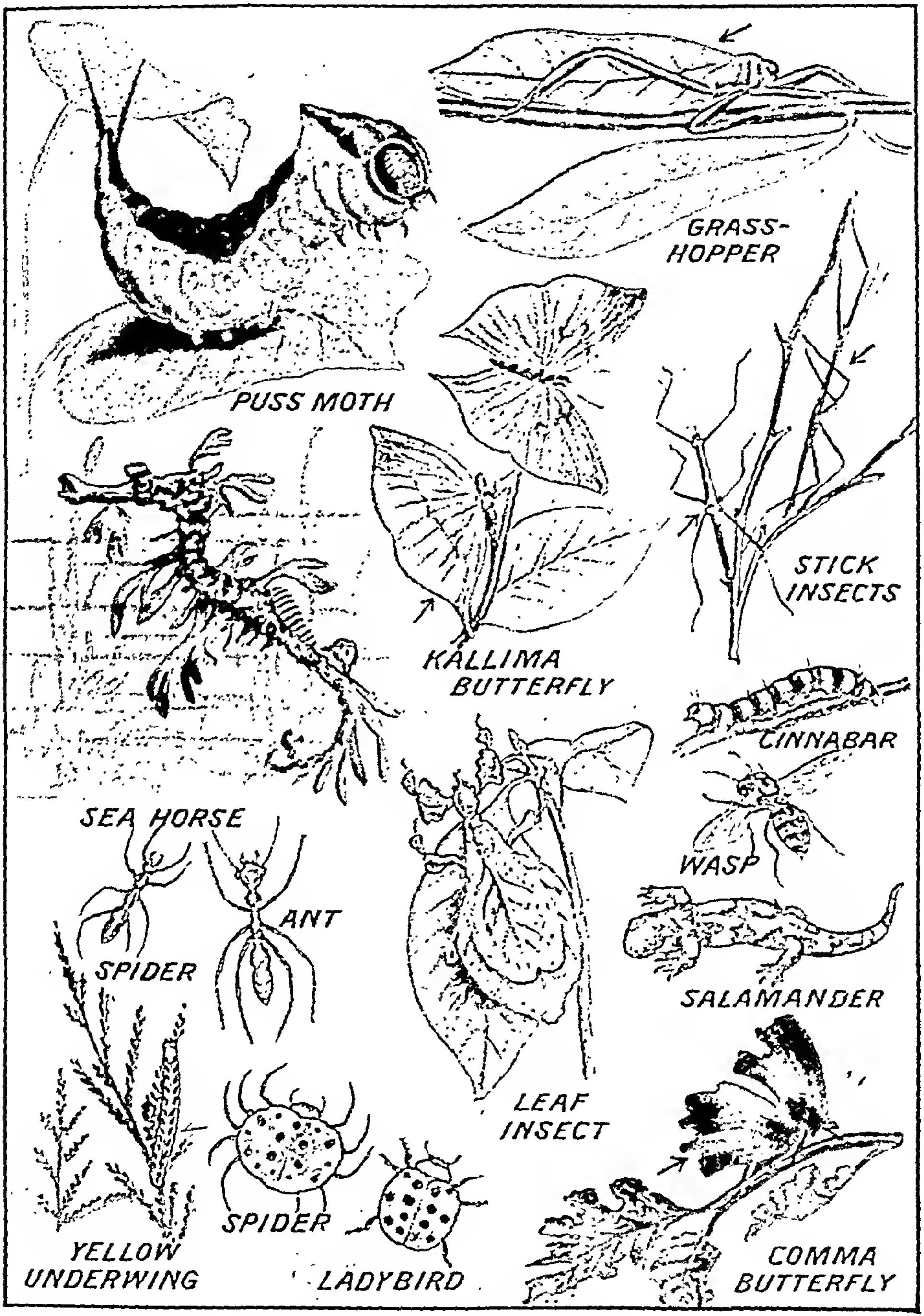


Fig. 14. Some extraordinary examples of self-preservation in Nature by camouflage and protective imitation. Some creatures have the faculty of resembling their surroundings in danger, whilst others can take on the appearance of animals repulsive to their enemies.

Fig. 15. An artist's impression of the inside of a Termite hill. Termites have a remarkable civilisation.

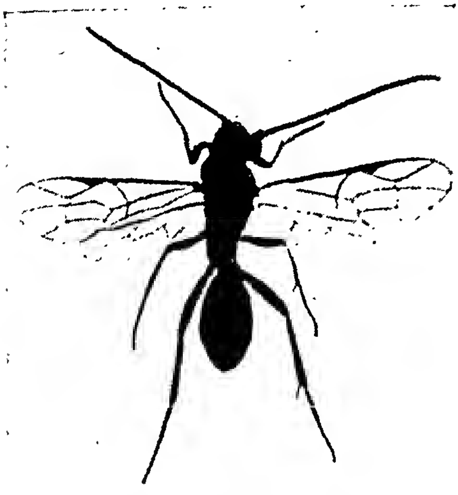


Fig. 16. Female Red Wood Ant, showing the wings. It is the largest British ant.

In such nests the ants keep "cows" and "milk" them. In the ordinary course of. events, many ants climb the surrounding plants in search of nectar. Here they discover the plant lice or aphides (Fig. 17) that exude a sweet drop of fluid when stroked with the antennae or feelers of the ant. The aphides are herded together and driven down below to the nest, where they are fed and kept specially for this sweet fluid which they exude.

In the south of England, some of the ants in their foraging on the wild thyme collect the caterpillars of the large blue butterfly. These likewise are driven below and pupate in the ant nest, from which they emerge the following summer as perfect butterflies (Fig. 18).

THE MOST DANGEROUS ANTS

Among the largest and most dangerous of the fighting ants are the Amazons that march in search of their prey in serried ranks like a terrible marauding army.

They raid nests of less war-like ants for the purpose of obtaining slaves. At least three species of ants keep slaves. When they raid another nest, they kill off the worker and warrior ants, and take back the pupae and these they hatch out as their slaves. Should they have cause to move their habitation, they take their slaves with them. These slave-keeping ants neither feed their young nor make their nests themselves, but depend entirely on slave labour. Beetles, spiders, crickets, and wood-lice, are sometimes found in ants' nests, and it has even been suggested seriously that they may be kept as pets!

The social life of the wasps differs from that of bees in the shorter life of the queen and the fact that the entire colony —excepting the queen—dies off with the winter frosts. The rain rots away the wonderful nest-ball of *papier mâché* that is made from wood-pulp stripped off

Fig. 17. Aphides, or "green fly", sucking the juice from a young rose shoot.

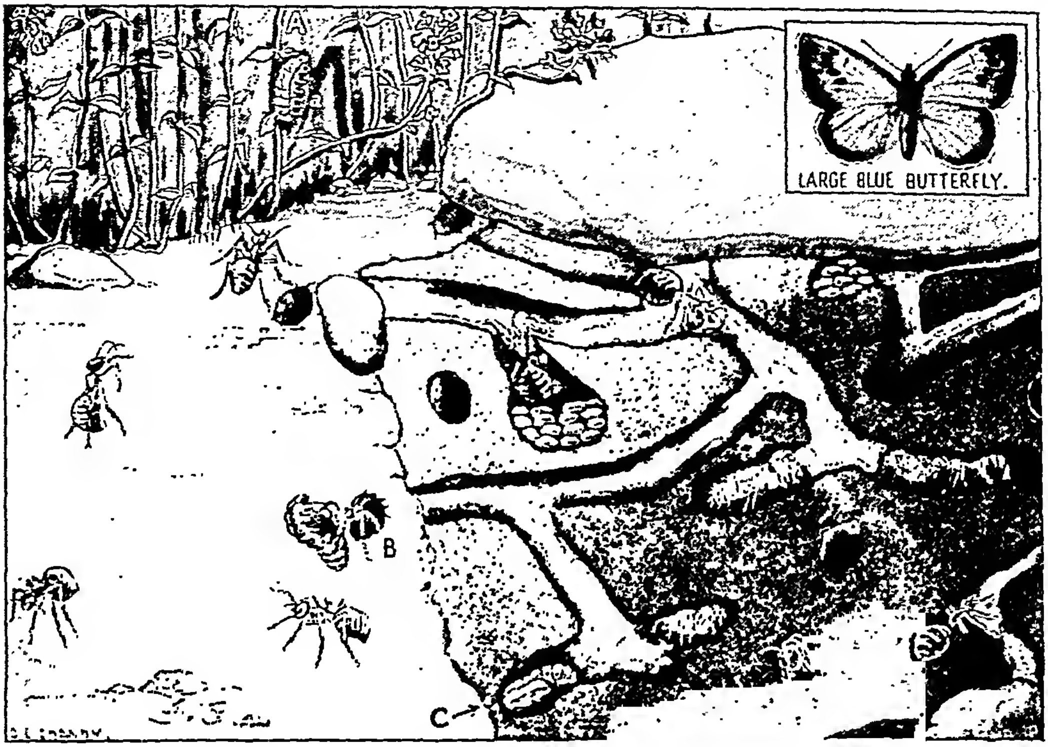


Fig. 18. The life history of the Large Blue Butterfly. A. Larva feeding on wild thyme. B. Taken by ants into the nest. C. Completes its metamorphosis into a butterfly in the nest. About a year lapses between the time of its capture and its release. Inset (at the top right) is the adult.

old fences and posts (Fig. 19) The young queen alone hibernates for the winter, to emerge and lay her eggs and rear her grubs.

There is only one "solitary" British wasp, and it makes its small spherical mud-nest in the heather. Among the social wasps, however, the wood-wasp lays its eggs in the nest of the red-legged wasp. There are no workers but only males and fertile females.

LIFE IN A BEE-HIVE

The social life of the domestic bee hive, with its various duties assigned to different workers, is well-known. There are the doorkeepers, who attack strange bees and sting them to death between the joints of their bodies, and ventilating bees who keep a current of fresh air in the hive by fanning it with their wings. Other workers collect water; others form the six-sided cells that make the maximum use of the minimum space, and in which eggs laid by the queen hatch into grubs. The queen lays thirteen times her own weight in eggs a year, laying 2,000 or 3,000 a day during the "honey-flow" of summer. Those that are given "royal jelly"—an extra rich food or mixture of pollen and honey—produce queens or fertile females. The others, furnished with plainer food, hatch into workers.

A hive may have 50,000 or more workers, and 2,000 drones or males. The workers hibernate for the winter after a ruthless killing of the drones. By their visits from flower to flower in search of nectar, their hair-covered bodies mix the pollen of the different plants, and thus help plant fertilization.

Between the joints of the hind leg is a fold or pannier that enables the bee to

carry back to the hive the pollen required there.

Bees do not seek honey, but nectar. Honey, as we know it is made by the bee in its honey-stomach, where cane sugar is turned into grape sugar by means of a ferment, or enzyme, called invertase. Over a thousand bees must work a lifetime to produce a lb. of honey for their flight-range is within a three-mile radius of the hive. As in the case of most of the lower animals, bees are partially colour-blind, and see red as black, green as yellow or blue, and see only the last in its true colour. Many creatures are wholly or partially colour-blind—for example, the bull cannot distinguish between a red flag and a grey one waved before it.

Wasps are frequent raiders of bees' nests, especially those of the humble bees that live in stone walls and banks. The big strong cuckoo bee, or *Psithyrus*, has no nest of its own. It prolongs its winter hibernation late into the spring, until the humble bees have their nests well started. In May and June it may be recognised by its dark, smoky wings, and its silent flight. The raiding wasp enters the nest of other bees and, strange to say, having conquered the bees guarding the entrance, is left alone. Once inside the nest, the cuckoo bee sooner or later fights and kills the queen, and carries on the cell-making and egg-laying herself. The worker bees, born from the earlier layings of the rightful queen, rear the grubs of the usurper.

OTHER INTERESTING BEES

Of the numerous other bees, perhaps the most interesting are the sand-bee, that burrows into sand; the long-horned bee that lives in the ground; the mason bee that plasters a mud-like nest; the carpenter bee that makes holes in wood; and the leaf-cutter bee that bites small semi-circles from rose-leaves, with which to line its cells. The last are short-tongued bees and are closely related to the wasps.

There is a good deal of misapprehension in regard to the bee's sting, which is a development of the ovipositor, or egg-layer. It is a sharp, needle-like instrument and contains two serrated barbs that lacerate the flesh. A popular belief is that the bee stings only once and then dies. When the bee uses its sting, the pain causes the victim immediately to brush it off, with the result that the bee has no time to withdraw its sting. The sting, engaged in the flesh by the barbs, is thus usually torn out of the bee's body and as it carries part of the entrails with it, the bee dies.

Flies are equipped with two flight-

Fig. 19. Nest made of wood pulp from old fences and moulded by the wasps into a plastic material. Inside the *papier mâché* ball is a remarkable series of chambers and passages.

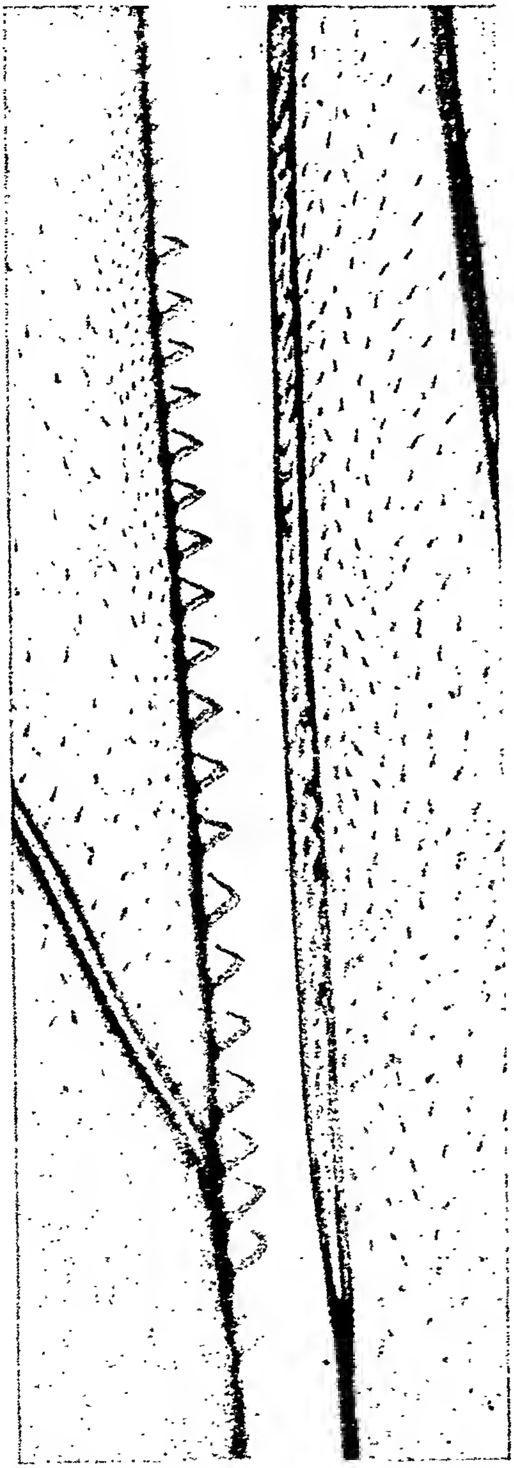


Fig. 20. The hook and eye in Nature. Bees' wings have hooks and eyes by which they are linked together for flight, a single wing being more efficient than two separate ones. Other four-winged insects do not follow the bee in this.

wings instead of four, as in the bee. If we examine the wings of the bee through a microscope we see that there are a number of little hooks, or *hammuli*, along their margins (Fig. 20). These enable front and hind wings to hook together to form a single flying plane in flight (Fig. 21). This is quite different from the flying arrangements of other four-winged insects, such as, for example, the dragon-flies and butterflies.

FUNCTIONALISM IN NATURE

Although a single pair of wings are more effective in flight than two pairs of wings—for they present a larger area to the air—the bee has to clean out the cells of the comb. If it were equipped only with a pair of wings, as is a fly (which has no cells to clean out) it would not be able to enter the cells, since the wings could not be folded over the back sufficiently to allow the insect to enter the narrow cell. Here, indeed, is one of the great marvels of Nature by which the bee is equipped according to the work it has to perform.

Ferdinand de Lesseps, the engineer of the Suez Canal, was forced, after thousands of men had died of malaria, to give up his attempt to drive a canal through the Isthmus of Panama. Little was known of malaria and how it is carried when de Lesseps made his ill-fated attempt. It was not until Dr. Manson and Sir Ronald Ross had completed a careful study of the disease and traced the life-history of the mosquito, that the construction of the Panama Canal became possible.

When the Americans took over the derelict works of the French enterprise they first set about exterminating the mosquitoes. They poured oil on the pools, in which the larvae spent the first part of their lives as aquatic "blood-worms", so that the free-swimming, air-breathing larvae were suffocated by the

oil on the surface.

It was subsequently discovered that another mosquito carries the germ of yellow fever. In Africa, the blood-sucking tsetse flies were found to carry the trypanosome, or germ, of sleeping sickness. Even the common house-fly of Europe has been proved a great carrier of typhoid. There are twenty-eight British gnats or mosquitoes, including four malaria-carrying *Anopheles*. These may be distinguished by the fact that they hold their bodies in a straight line when at rest, the other gnats having a humped-back appearance. It is usually only the female mosquitoes that do the "biting". In autumn the frosts kill off the short-lived males, leaving the females to hibernate through the winter. The male gnat is recognised by its more densely-feathered antennae; the female by her pointed abdomen (Fig. 22).

THE "DADDY LONG-LEGS"

Related to the gnats is the "daddy long-legs" or—more scientifically—the crane-fly. Its "grub", or larva, is the "leather-jacket" so destructive of the roots of grasses. In Africa and parts of Europe the so-called army-worm, a fly-grub related to the daddy long-legs, causes wide damage by the migrations of armies of larvae to new feeding grounds. In the form of a mass of maggots extending to several feet in length and an inch or two in breadth, they move through the woods like a grey column. The Hessian fly, one of the gall-midges terribly destructive to American wheat, is so called because it is said to have been introduced by Hessian troops imported at the time of the War of Independence.

The life-histories of insects are most fascinating and particularly so where parasites are concerned. In the country on a summer's day we often see beasts "gadding" about the fields—running wildly with their tails in the air, alarmed

Fig. 21. In Fig. 20, the bee's wings are uncoupled. Here we see what they look like when they are linked together by the hooks as in flight. Notice how securely the two wings are held together, edge-to-edge.

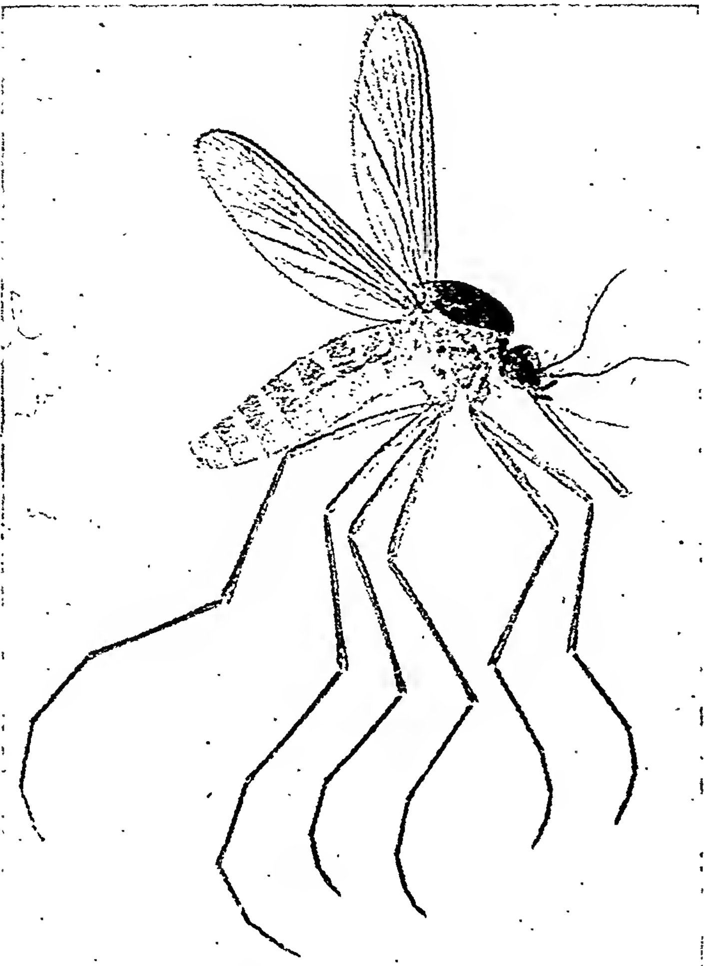


Fig. 22. A female gnat (*culex pipiens*). There are twenty-eight British gnats, four malaria-carrying. Only the females bite.

and horses. The American deer bot-fly has been claimed to be the world's fastest flying insect with a speed of eight hundred miles per hour, but this amazing claim so often quoted has been clearly refuted in recent experiments.

"Where do flies go in winter time" is a popular conundrum propounded in regard to our common house-flies. There is no *mystery as to their* whereabouts, however, for those that survive the frosts hibernate in warm cracks and crevices, to emerge in the following spring. It is usually the lesser house-fly that is abroad in spring and early summer, the common house-fly coming later.

The house-fly, the blue-bottle, and a large number of carrion flies, serve a useful purpose in Nature as scavengers, laying their eggs (see Fig. 29, page 479) in offal, waste, and decaying flesh, so that their grubs eat the refuse.

at the buzzing flight of the gad-flies and warble-flies. These insects lay their eggs on the legs of the beasts, whence they are licked into their mouths. On hatching, they work their way into the intestines where they grow to full size. They then bore through the muscles to the skin of the back, where they pupate and form large warbles from which the adult warble-flies emerge in summer.

The bot-fly lays her eggs on horses' legs, and they, too, are licked into the mouth and pass their lives in the horse's intestine.

The gad-flies, close relatives of the tsetse-fly, inflict serious bites on cattle

How does a fly walk upside down on the ceiling? If we examine its feet under the microscope we see that there are little hairy cushions. These emit a sticky excretion that makes it possible for the fly to walk up a window pane or to hang head downwards from any object. If we put the tip of a fly's tongue under a powerful microscope, we see still another cushion-like pad containing a network of tubes. When a fly feeds on crumbs on the table we can see how it lowers its curious

tongue on to the food. Actually, it secretes a slime that partially dissolves the food, thus allowing the food to be sucked back through the tubes of the tongue.

Just above the flight-wings there are *two tiny knobs, or "halteres". These* are the balancing organs, formed from a degenerate pair of wings. If one of these halteres is removed, the *fly* cannot keep its balance. They serve the same purpose as the little balancing channels *in our ears by which we feel giddy when* we have twirled round too much and disturbed their contents. Nature has many ingenious and marvellous balancing arrangements—in the lobster they take the form of a number of grains of sand in a pocket near the head. In a a fish, they are marked by the lateral line along its side.

The flea, a subject of misplaced humour and idle levity, is actually a *fly* that has "come down" in life. Adapting itself to the life of a blood-sucking external parasite, it has lost its *wings and flattened its body sideways,* so that it will not easily get brushed off its

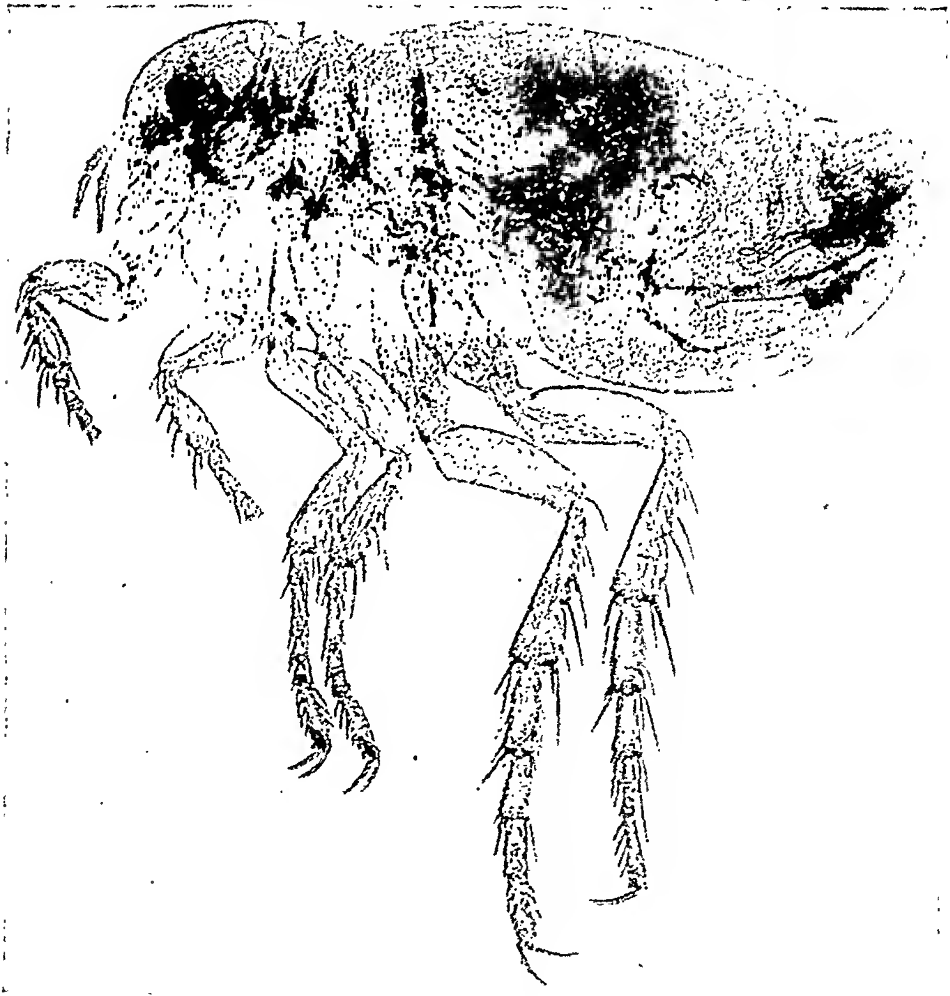


Fig. 23. A photomicrograph of a flea. Notice the great hind legs for jumping long distances.

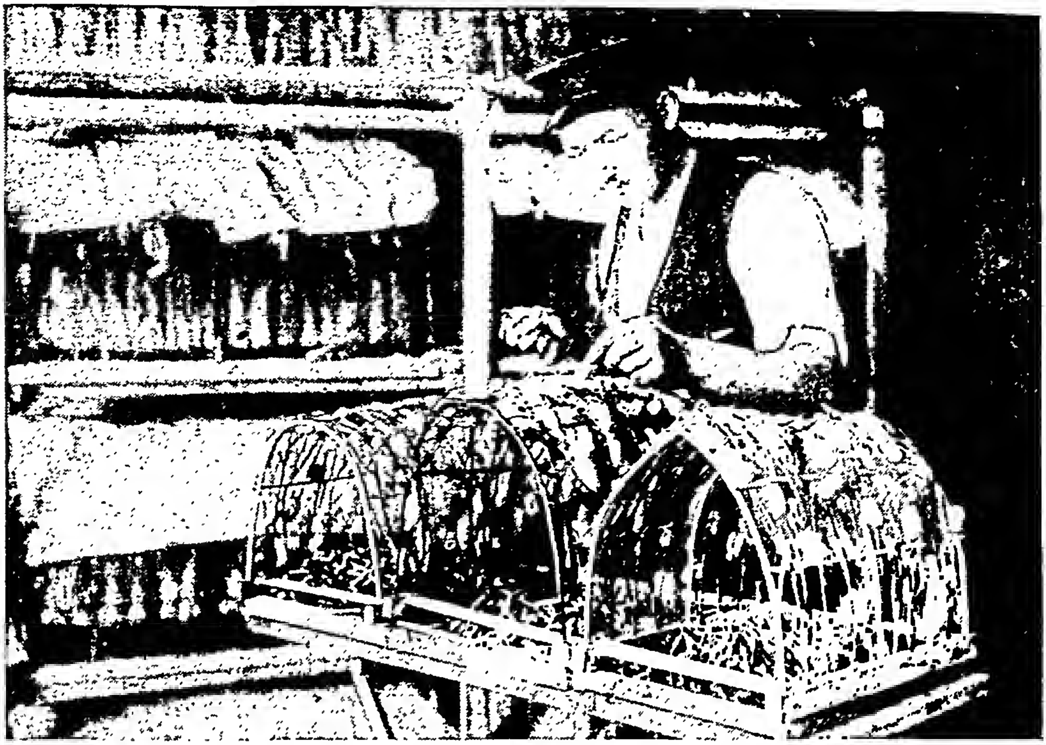


Fig. 24. Breeding silkworms. When the cocoons have been completed they are all gathered together (as is shown above) and the silk wound on a simple machine.

host. Its main progression is by jumping. It can sometimes clear a foot rule, and if man could jump as high in proportion to his size, he would be able at one bound to clear the famous Woolworth Building in New York.

Some seven hundred species of flea are known to science and most of them have their own particular animal hosts. The human flea, *Pulex irritans* (Fig. 23) is normally known to occur on only one other animal besides man—the badger. The famous performing fleas of the circus are usually dog-fleas. They are comparatively large and are able to run quickly and be attached to miniature carriages, etc.

In hot countries the chigoe fleas actually burrow into the flesh of their hosts. The pregnant female chigoe of South America gets her abdomen so swollen with eggs that it reaches the size of a small pea, completely enveloping her head and thorax! Similarly, the female termite's abdomen becomes distended to colossal proportions, for she is little more than an egg-laying machine.

Although most people suppose that migration is confined to birds, it is a fact that insects also adopt this method of travel. Apart from the familiar mass food-migrations of the army worm and the locust swarms, there are annual migrations of butterflies. The Painted Lady and Red Admiral travel across Europe to the British Isles. The Camberwell beauty and Large White move southwards from the Baltic countries, while the Great Monarch or Milkweed butterfly of North America migrates in flocks from the Hudson Bay area southwards, to hibernate through the winter in the United States and Central America. Sometimes the gales blow thousands out to sea, and a number of specimens have crossed the Atlantic, reaching Britain

and France. Others have crossed the Pacific to establish themselves in Hawaii and Malaya. The Silver Y moth—a chocolate brown moth with a silver Y on its wings—migrates in swarms from the Continent to Britain. Great flights of these insects have been observed passing the Muckle Flugga and St. Catherine's Lighthouses on their migration northwards.

The sexual senses of moths and butterflies are mysterious and marvellous, and especially so with the Emperor Moth. If a female be enclosed in a small box and taken outside, the males from miles around will sense her and fly to the box. Some theories hold that this is due to scent, others that it is due to an electro-magnetic discharge akin to wireless waves. There is a similar attraction with the Oak Egga and a few other moths.

The so-called silkworm is really an oriental moth closely related to the Emperor of our moors, the silk being the spun thread from its cocoon that protects the pupa or chrysalis (Figs. 24 and 25).

We usually think of moths as dull insects of the night, but actually they are far more numerous than the butterflies. We have some sixty British butterflies but well over two thousand moths. Some, such as the Peach-blossom, the Oleander Hawk, the Burnished Brass and the Buff Archer, are as beautiful as the butterflies. The biggest British moth, the Death's Head, is found over Europe and Asia, and takes its name from the outline of a skull that is clearly marked on its back.

A number of moths fly by day, notably the Six-spot Burnet, the Cinnabar, the Magpie or Gooseberry moth, and the Silver Y. The lovely little China Mark is a pond-side moth, whose

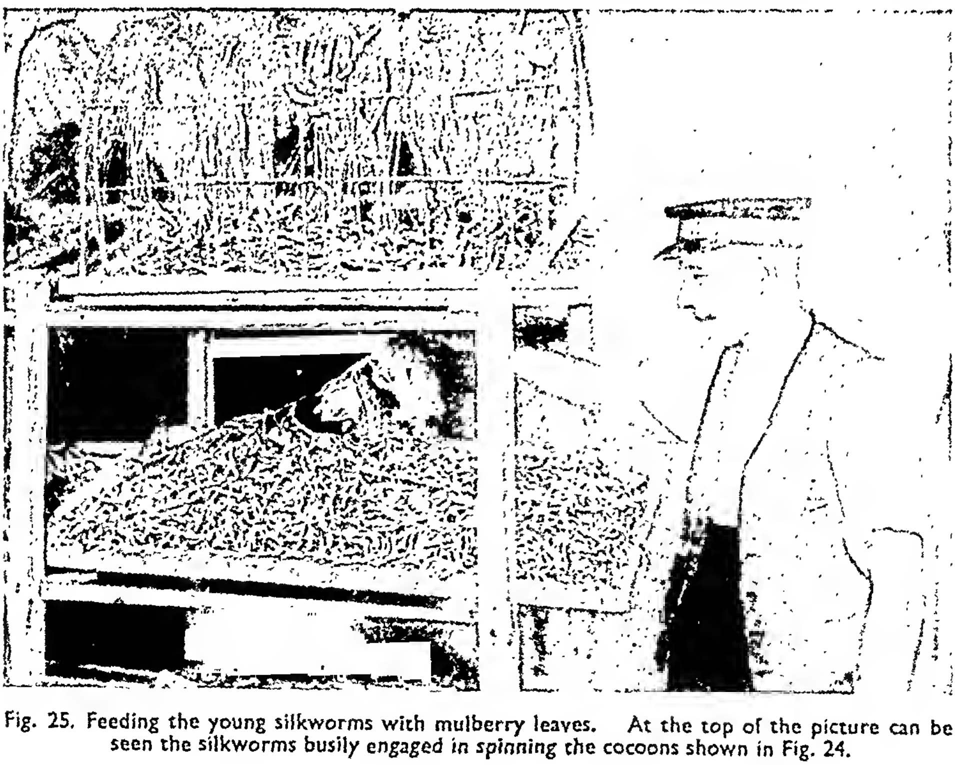


Fig. 25. Feeding the young silkworms with mulberry leaves. At the top of the picture can be seen the silkworms busily engaged in spinning the cocoons shown in Fig. 24.

Fig. 26. Photomicrograph of a Tiger Moth's head. A butterfly's antennae or "feelers" end in little flattened knobs; a moth's are, in most cases, without this feature.

caterpillar lives under the water, feeding on the bases of reeds and weeds, but breathing air from the surface.

We distinguish between a moth and a butterfly by the fact that usually a butterfly has a more slender body, and slender antennae clubbed at the tip (Fig. 26). Above all, it rests with its wings folded over its back, with the under surface of the hind wings showing the protective colour that camouflages it from foes. On the other hand, the moth has a thicker and shorter body, very feathered antennae and folds its wings flat across its back with the protective colour on the upper surface of the fore-wings. There are some exceptions, but these brief details provide a rough guide.

Adult moths and butterflies do not grow, of course, but when they emerge from the pupal case they have quite tiny crumpled wings. These rapidly grow to full size and dry before the insect flies.

Moths do not make holes in clothes—it is their caterpillars that do the damage.

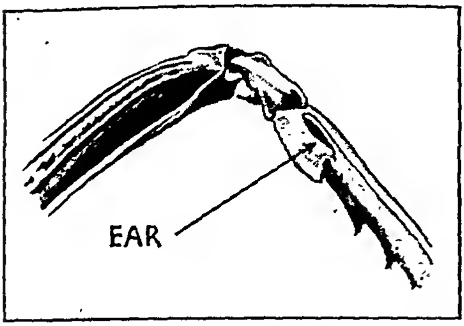
Some of the scales on male butterflies and moths are transparent and give no colour. They are specialised as scent-scales, giving off a faint odour in courtship. In the common green-veined cabbage-white butterfly this scent is like oil of lemon.

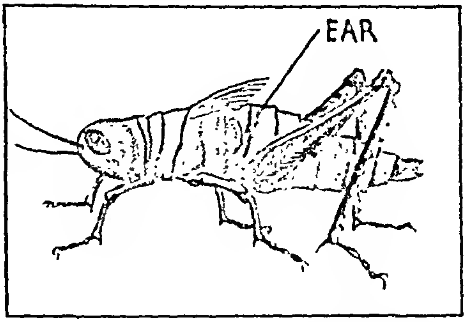
There are not many insects that utter calls, unless in a mechanical way, but the big Death's Head Hawk moth occasionally utters a squeak. It does this by forcing the air from its *tracheae*, or air-tubes, through its snout. This moth has so short a tongue that it cannot sip nectar from many deep flowers and thus it often raids the bee-hives for honey.

DEATH WATCH BEETLE

Another insect-caller, the Death Watch beetle, makes a peculiar tapping noise by bumping its hard, chitinous head against the walls of the galleries it has made in badly ventilated roof timbers. The tapping is a call between the sexes, as is the drumming or tapping of the Spotted Woodpeckers. The cricket and grass-hopper are "fiddlers", the former rubbing a leg backwards and forwards across a striated part of its back, and the latter rubbing its two legs together on a hard ridged sound-box-like arrangement. The long-horned grasshopper, by the way, has its ears or sensory organs in its legs (Fig. 27), whilst the short-horned grasshopper has its ears in its side (Fig. 28).

Dead birds and other small creatures are seldom found in the country—apart from dead shrews and moles. The male shrews and moles fight so fiercely amongst themselves in the mating season that deaths are many, but they are so "musty" in taste that cats and birds usually discard them. Most small corpses, however, are quickly devoured by the carrion-eaters and in this respect the scarlet and black-banded Sexton or Burying Beetle serves a useful purpose. Finding a dead bird, it usually burrows





Figs. 27 & 28. Ears of long-horned (Fig. 27, left) and short-horned (Fig. 28, right) grasshoppers.

the soil around it until the corpse sinks into the hole or grave. When it has been covered over, the beetle lays its eggs within, its grubs feeding on the dead bird. Other insects similarly lay their eggs in carrion or filth (Fig. 29).

In our ponds there is a big fierce water-beetle, the Dyticus, a killer of small newts, tadpoles, and fish fry. It is an air-breather and periodically comes to the surface, raises the tips of its hard wing-cases, and so collects a reservoir of air under them with which it dives to hunt the bed of the pond.

WHAT IS A WATER-SCORPION?

The common Water-boatmen and Water-scorpions we see on ponds, also the pond-skaters running over the surface, are not true beetles but bugs, as their biting mouth-parts—lying at an angle—suggest. The Water-scorpion obtains it air supply with its "tail". This consists of two hollow tubes fitting together to form an air pipe or periscope pushed to the surface for fresh air. The Pond Skater and the little silvery Whirligig Beetle can run about the water surface without getting wet. These insects are so light that they do not break the surface film of the water.

Certain beetles are easily noticed because of their long curved proboscis, which in some cases is developed like a little trunk. These are the very numerous and destructive weevils. Their defence from foes is simple. When any vibration amongst the plants tells them of an approaching foe, they merely fall off and lie limp below, shamming death and usually escaping detection. Entomologists collect them by first spreading a sheet of paper, or opening an umbrella, beneath a shrub, and then tapping the plant with a stick.

We have already stated that the glow-worm is actually a beetle, but you may wonder how a glow-worm "glows". This is a case of biological oxidisation very similar to (although not quite the same as) the phosphorescent lights of deep-sea fish, the luminous centipede, the

Fig. 29. The Larva of the common Hover-fly photographed lying in a bird's corpse.

Fig. 30. The tiny "frog-hopper"— a species of bug—feeding on a leaf. It can be recognised by the circle of froth around it.

luminous cave-moss of Dartmoor and elsewhere, and the fireflies of the tropics. In the glow-worm, the light is a double organ, carried very carefully beneath the "tail". It is the terminus of many air-tubes or tracheae, and the insect is able to control the flow of air or oxygen on to a kind of chemical called luciferin, thus brightening or diminishing the light according to its nervousness or excitement. The "glow" is chiefly used by the wing-less female to attract the flying male beetle.

In any field-pond there is a wealth of insect-life in summer. Dragonflies, mayflies, caddisflies, gnats, and many other aerial insects spend their larval stages under water, breathing air by varied means.

The mayflies are remarkable for their numerous moults, and although it is not always true to say that they live only for a day—a fallacy associated also with butterflies—their lives are very brief and depend largely on the weather. One of the Canadian mayflies (*Stenonema canadensis*) passes through forty to forty-five moults from its aquatic larval form before hatching into the flying adult. At each moult it increases its size and external structure, although many other of its relatives have but five or six moults. The anglers have different names—such as "Green Drake" and "Grey Drake"—for the different moults of the mayfly.

TYPES OF BRITISH MAYFLY

There are over fifty British mayflies, and it is probably the constant need for changed structure to fit into their unstable environmental conditions as much as mere growth, that has evolved this complicated series of moults in the mayfly history. This moult is called an *ecdysis*, because it is a complete climbing out of the old skin and growing a new one.

Similar moults occur also with crustaceans, such as crabs and spiders.

It is in the group of orthopterous insects to which the mayfly belongs, that we find the termites, or so-called white ants, of the tropics. These are really social descendants of the cockroaches, and the North Australia giant termite *Mastotermes* has wings very similar to those of a cockroach. The queen of the large African termite lays at least thirty thousand eggs a day or ten million a year, but the Natal termite lays only about a tenth of this figure.

The so-called book-lice that are to be seen like microscopic insects crawling over old paper, and the "bird-lice", also belong to this orthopterous group.

The last great insect-group, little less numerous than the beetles, is the *Rhyncota* or order of bugs, whose members are usually recognised by their beak-like mouth-parts. These include the frog-hopper, a feeder on plant-juices

(Fig. 30). It bites the stems and froths up the sap with its saliva into the well-known "cuckoo spit" of summer. Therein it deposits an egg or two, the protective "cuckoo spit", unable to dry up in sunshine, shielding the young froghopper from the attention of birds while it feeds on the sap.

A vast number of sap-sucking plant-pests belong to the bug tribe, especially the greenfly or aphis, which has four wings and therefore is not a true fly or dipterous insect. To this tribe also belongs the black fly of our broad beans, the scale insects of our fruit trees, and the apple capsids. On the Continent there is the well-known *cicada*. It is a stout-bodied pest of trees and its underground larval form may last for as long as seventeen years. The adult form, hatching when conditions are suitable, lasts only about four weeks. The famous Chinese-lantern fly—a prettily coloured insect like a paper lantern but not luminescent as its name might suggest—is another bug. So are such creatures as the water-boatman, water-scorpion and the pond-skater.

THE INGENIOUS BED-BUG

The infamous bed-bug is not native to Britain, but came from Asia, and was first noted at Mortlake near London in 1583. Cleverness amongst insects is not very noticeable but the bed-bug has given observers many surprises. For instance, when beds have had their legs stood in liquid preservative to prevent the insect crawling up, it has crawled up the walls, on to the ceiling, and then dropped down on to the bed from above!

The cockroach and the earwig show great care and wisdom in the protection of their young. The former are born from purse-like cases that the female carries away in time of danger. The earwig broods her eggs under a stone like a hen hatching out her chickens.

On the other hand there is a noticeable lessening of intelligence in the centipedes and spiders, which so many people confuse with the insects. A feeding centipede has had its body removed save for the first few segments, yet still went on feeding, the food passing out of the cut intestine. Not all centipedes have the hundred legs from which they are named. The common centipede has thirty legs, while some other species have two hundred and forty-two. It is a curious fact, however, that whatever the species, their bodies always have an odd number of segments.

SUICIDE AMONG ANIMALS

By counting their legs you will see that the scorpions and ticks are related to the spiders, or to the eight-legged group of jointed animals. There is an old myth that the scorpion commits suicide by stinging itself, but this is not the case. Other animals also occasionally appear to do so. A chimpanzee at a northern Zoo once climbed on a box, put its head through a noose in its play rope, and then slipped off. A cuttlefish in its aquarium tank discharged so much sepia from its ink-sac when alarmed that it choked the tank and suffocated itself. We must conclude however, that man is the only animal with sufficient intelligence to commit suicide.

Spiders, and their allies the scorpions, differ from insects in more ways than in their possession of an extra pair of legs (Fig. 31). They have no separate head or antennae, and their simple, single eyes are on the same body portion as their limbs. Not all the fourteen thousand known varieties of spiders spin webs. That habit belongs to a special web-making group and the web is not the spider's home, but its snare. In the distant past, the spiders that lined their retreats with silk may have left a

Fig. 31. The garden spider spins its web.

stray strand or two over the edge, and by this a fly was accidentally entangled. From this they may have developed the habit of leaving strands, and even increasing them, to catch more flies, and so the web-making habit reached its present proportions.

A typical spider's web consists of twenty-six opaque radial threads and twenty-four transparent transverse ones on which are drops of viscid fluid to catch the prey. The average web contains 87,360 globules of this sticky fluid, but a large one of 14-16 in. diameter may have 120,000. Such a web may be made in forty-eight minutes and it is so light that 27,600 webs weigh one pound. The thread is so fine that a ball of thread the size of a pea could be unwound and would stretch from Liverpool to London.

Because spider threads are finer than the thinnest strands of platinum wire, they are used by scientists for marking the sight-lines on telescopes, microscopes, and theodolites. A famous optical works at York used to send a man on to Strensall Common to collect spiders and gossamer. The captive spider was put in a box, and when released, spun a thread to lower itself

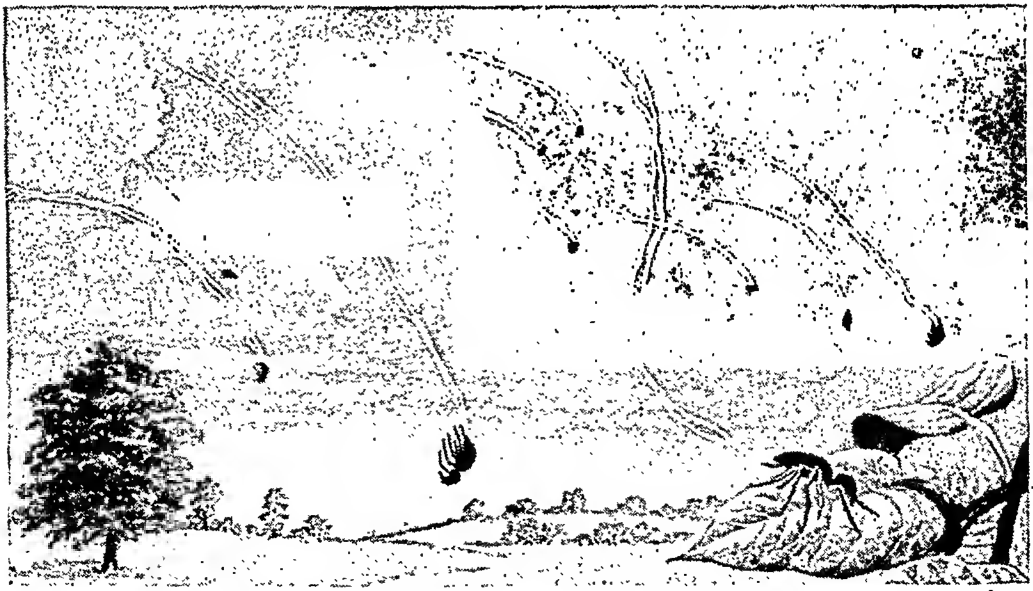


Fig. 32. Nature's parachutists. Here we see an artist's impression of spiders being carried to new haunts by gossamer threads they have put out in the breeze.

to the ground, but as fast as it spun, the thread was wound round a wire frame. A hundred yards of thread, or twenty frames full, could be obtained from a single female spider. Such a thread marks the meridian at Greenwich Observatory.

Gossamer is the autumn production of young spiders that climb onto a fence, spin a thread by which they anchor themselves, then spin lengths of double thread into the breeze. This pulls like a parachute until eventually the young spider bites through the anchor thread and floats away to new haunts (Fig.32).

In addition to the web-spiders there are the interesting water-spiders of our ponds. They arrange a big bubble of air in the pond-weeds for their young (Fig. 33). The big bird-eating Mygale spiders and poisonous Tarantula spiders of the tropics sometimes reach England in crates of fruit. "Harvest spiders", by the way, are really mites.

THE TRAP-DOOR SPIDER

The trap-door spider digs a short, broad tube in the ground and fixes at the top a trap door of moulded earth on a silk hinge. Insects visiting the top are caught and dragged in. The raft-spider, which lives on the borders of lakes, makes a raft of leaves and floats on it, but it can run over the surface and sometimes plunges below. The zebra spider stalks insects on a sunny fence with cat-like movements. Before leaping on its prey it first attaches a silk thread to its jumping point to ensure a safe return.

Most spiders die in the winter, but a number of females live two or three years. As most female spiders devour their husbands almost immediately after mating, the sexes cannot be kept together when under observation.

When we turn over old stones or damp logs in the garden, we often find squat,

Fig. 33. The water spider in its nest.

little, many-legged greyish creatures usually called siss-lice, wood-lice, pill-bugs, or slaters. Many people assume these to be insects, forgetting that they have too many legs. Although no one would suppose it, they are a link with the seashore, being crustaceans—relations of the crabs and lobsters that in the long story of evolution have taken to a life in damp spots inland. A study of their structure shows that they are closely

related to the shrimps and the sand-hoppers of the seashore. Of course, there are many freshwater crustaceans, too, such as the freshwater shrimp and the so-called water-flea or Daphnia that is much used as food for aquaria fishes.

THE CRAB'S LIFE-STORY

The life histories of crabs and lobsters are amongst the most fascinating in nature. It is difficult to realise that the active little free-swimming, tailed larvae of the crab later sinks to the bottom of the sea owing to the growing weight of its carapace or hard skin, and that it finally ends its days running sideways on the shore. Many creatures in the seas begin their life in a free-swimming stage, however, and continue to roam about the water until their changing forms weight them down to a life on the bottom. Other examples are oysters and mussels before they grow their shells. We can notice at once that the crabs and lobsters, and their relatives the shrimps and prawns, have peculiar eyes that stand on stalks. For this reason they are grouped as stalk-eyed crustaceans. Internally, they have a marvellous structure for masticating their food, called the Gastric Mill. It is much on the principle of the bird's gizzard, but the chamber has hard plates of chitin on its wall, and these crush the food like millstones.

It is not the "back" of a crab that we see, but its carapace—that is to say, the head and thorax or chest are not separated in the crustacean as in the insect. If we turn one over we see its abdomen, or "tail", tucked underneath. The lobster also tucks its "tail" underneath, but normally when feeding it crawls about with its body raised on its many legs. The tiny pro-legs under its mouth are rapidly rotated to kick food into the mouth, and also to keep a fresh current of water passing over the gills under the carapace. If it is suddenly alarmed, the lobster brings its tail under its body so rapidly that it shoots backwards into some nearby hole or retreat. Except in some rare deep-sea Pacific forms, lobsters are not pink in the sea but a deep bluish black; they turn pink on boiling.

In its chief nerve-centre on the head, the lobster has a tiny cavity communicating with the outside by an even smaller cavity, in which are a few grains of sand that serve as the lobsters' balancing organ. (We have already referred to this.) Periodically a lobster must cast its skin to grow, but its new soft skin quickly hardens. In casting its skin it loses its old balancing cavity and the new one has no sand-grains, so that at such times the lobster has been observed to pick up pinches of sand with its claws and drop them over its head, repeating this until a grain gets into the fine cavity. One scientist ingeniously strewed the bottom of the aquarium with iron filings instead of sand.

A lobster got one of the filings into the cavity that controls its equilibrium. The scientist then brought a magnet near it, so attracting the filings to the top of its head and causing the lobster to turn completely upside-down.

HABITS OF THE HERMIT-CRAB

The hermit-crab is well known for its habit of taking an empty whelk-shell to protect its soft abdomen from foes (Fig. 34). Sometimes a sea-anemone will live on the whelk-shell (Fig. 34) and when the growing hermit crab moves house, it moves the sea-anemone to its new shell. This is a good example of an arrangement in Nature by which different animals live together for mutual benefit. They do not harm each other or live at another's expense as in parasitism, for the crab has the advantage of the sea-anemone's stinging tentacles to frighten away foes. On the other

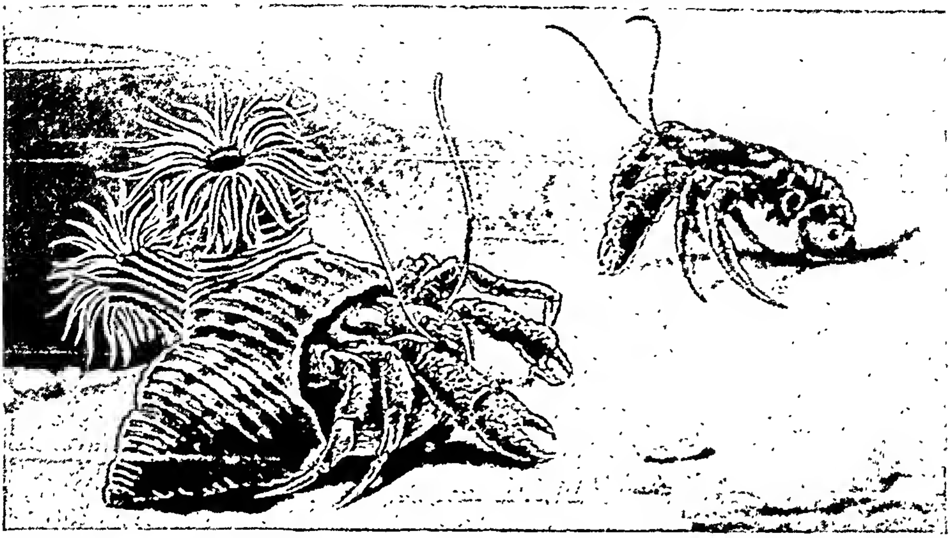


Fig. 34. A hermit-crab (left) in its borrowed shell and (right) looking for another shell at moulting time. The hermit-crab has to find a shell to live in as otherwise its soft, unprotected abdomen is a vulnerable target for its enemies. Sea-anemones frequently live on these shells.

hand, the sea-anemone can feed on the scraps remaining from the crab's meals.

Sometimes tiny fishes will live in the entrance to the sea-anemone's mouth, as under a jelly-fish, darting there from their larger foes who dare not risk the tentacles. Sea-anemones are not flowers, but animals, with a column-like body, a disc-like foot by which they anchor themselves to rocks, and a fringe of stinging tentacles that numb their prey and roll it into the body-cavity.

There is also the little pea-crab that lives inside the common mussel; and the barnacles that are really stalked crustaceans. They live in little shell-like cases on the rocks and piers, but are free-swimming in their early stages. Later, in their "shells", with their bunch of tentacles kicking actively, they whip any passing food out of the sea.

We cannot go far on the seashore without finding shells—the empty homes of "shell-fish". Really they are not actually fish but molluscs and resemble the snails of the land, and their shell-less relatives the slugs. Most molluscs have some kind of a hard shell, either a single shell—as in the whelk, the winkle, the garden snail and the famous cowrie of the tropics—or a double, hinged-shell as in the mussel and oyster. We do not recognise the octopus and the cuttlefish as molluscs, for they have lost their shells save for that degenerate piece that we call "cuttle-fish bone" and give to canaries. A mantle of soft tissue has completely overgrown the shell and has also produced those long tentacles with suckers by which they seize their prey.

Stories of octopods attacking ships and men in the terrible scenes of some novelists are allied to the stories of eagles that carry off children, and of sea-serpents wrecking ships.

HOW WE GET PEARLS

The story of the pearl is one of the most fascinating in all shell-fish life (Fig. 35). Most shells are lined with nacre or mother-of-pearl that is secreted by the mantle. When certain parasites

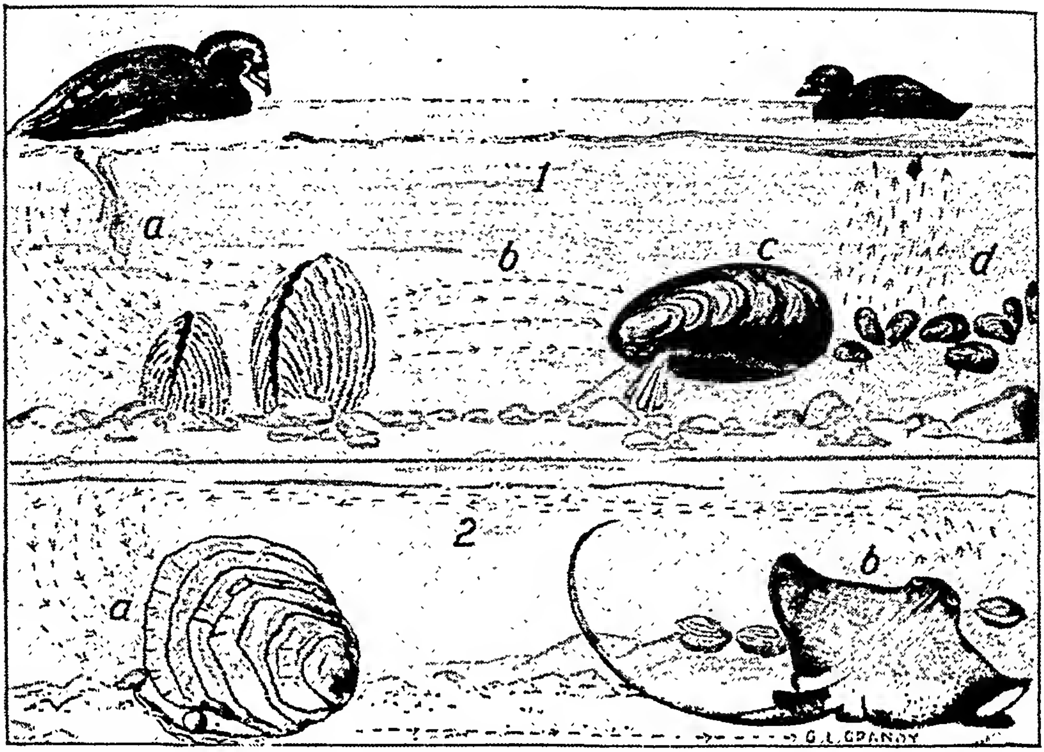


Fig. 35. The parasitic trematode worm plays an important part in pearl-formation. In the upper picture (1) we see how: (*a*) the worm's larvae leave their host, the scoter duck, to lodge in cockles; there they produce fresh larvae which pass (*b*) into mussels (*c*) and (*d*). In the mussel at (*c*) a pearl is formed, but those at (*d*) are eaten by another scoter duck, so completing the cycle. The lower picture (2) deals with another life-history: that of the oyster-visiting trematode. The trematode egg leaves the ray (*b*); hatches out in the sea; enters the oyster (*a*), there either to form a pearl and die, or else to be eaten, inside the oyster, by the same ray (*b*).

get into the mantle and set up an irritation, the oyster or the freshwater mussel secretes layer after layer of nacre to encase and kill it, and so the globular pearl is formed inside the oyster.

Many strange hosts figure in the life-history of these parasites. In the case of the oyster-pearl, the egg of the trematode parasite hatches in the sea and the free-swimming larva enters and infects the pearl oyster. Here the larva may cause the formation of a pearl and its own death, or on the other hand, it may become encysted and eventually grow into a larval trematode worm. The pearl oyster may now be eaten by a file fish, in which the larva grows into an immature tape worm. The file fish in return, may be eaten by a ray, in which the larva becomes an adult tapeworm, and produces eggs that are set free into the sea. Or the pearl oyster itself may be eaten by a large ray, the same thing happening, and the cycle beginning again. Many dangers must be avoided before each stage can be accomplished; hence the comparative scarcity of pearls.

With the mussel pearl of the Lakeland and Scottish rivers, the trematode worm lives as an adult in the scoter or black sea-duck. It produces eggs that give rise to free-swimming larvae. These may find their way into the edible cockle, there budding into further larvae that migrate into the sea. Here they may get in a mussel-bed and enter the edible mussel, where pearl formation in the mantle may kill them. Sometimes,

before that can happen, the mussel may be eaten by a scoter duck, which feeds on shell-fish, and thus the cycle starts again.

The story of the limpet shell clinging so firmly to the rock is an example of the use of atmospheric pressure, for the flat foot of the limpet is pressed so firmly against the rock that there is no air space and atmospheric pressure causes it to "stick". So effective is its grip of the rock that "to stick like a limpet" has become a popular phrase. The limpet secretes a weak acid that dissolves the rock, causing a small depression in which the creature rests. At high tide the limpet may roam far, but it has a strange homing instinct and usually returns to the same spot to rest during the next ebb tide. Molluscs usually have one siphon with which to suck in water and food and another to squirt out waste.

Some bivalves, such as the scallop, move through the sea by opening their two shells and closing them suddenly. The octopus and cuttle fish suddenly eject water from their siphon, to shoot rapidly through the water. In times of danger they eject a "sepia" smoke-screen to hide themselves from view. This fluid was formerly used in the manufacture of sepia ink, as the fluid of the purpura—or dog-periwinkle—was collected to make the royal purple dye of the ancient Phœnicians.

HOW THE COCKLE MOVES

The cockle moves in jumps by rapidly jerking its foot, but it often lies half-buried in the damp sand. If anyone approaches, it "spits" loudly, exhaling water from its siphon as it rapidly buries itself.

In these bivalves the adductor muscles, which hold the two valves together, are of such great strength that when the

Fig. 36. Living coral polyps photographed under water at Tortugas. Note the protruding tentacles.

shells close on beaks and feet of birds probing the shore, the birds often die of starvation through being unable to remove the bivalve. For a similar reason, the giant clam of the great barrier reef of Australia is greatly feared by divers.

On the other hand, the starfish raids many oysters, gripping each valve with its sucker feet and exerting a continuous pressure until it tires out the oyster.

THE SNAIL'S TONGUE

The pholas shell, or piddock, bores into the solid rock, and, as in the case of most molluscs—such as the garden snail—it has a ribbon-like rasping tongue with hundreds of teeth. As the rows of teeth wear out, the ribbon moves up to bring fresh rows of teeth into play. This creature is also believed to secrete a weak acid to assist it in its boring activities.

At first glance the snails—the "shell-fish" of the land—may not impress us, but they have some interesting points. For instance, in their courtship some species fire tiny flint love-darts at one another and, in early summer, these may sometimes be found. They look like little, half-chalk or half-flint bayonets, rounded or smooth, with two or four lateral blades. The shells of most snails curve to the right, but rarities prized by collectors are "anti-clockwise". Snails leave a slime trail because they need moisture upon which to glide by contracting and expanding their solitary, fleshy foot. Their eyes are on the ends of stalks that are even longer than those of the crabs. If touched, these eye-tentacles turn inside-out like the fingers of a glove that has been peeled off the hand.

The inhabitants of the rock pools, wherein the children paddle on their seaside holidays, are always interesting even to the scientist. There are the jelly-fish—floating plate-like creatur with stinging tentacles hanging down a bunch. Their life-story is anoth surprise, for the egg drifting in the s becomes attached to the bed where grows up into a cup-like column wi a fringe of tentacles. The cup divid into partitions that resemble a stack saucers, each of which floats off in the sea, turns over, grows a bunch tentacles from the middle, to form t jelly-fish we see drifting with t current.

On the shore we find also curio gristly yellow masses fixed to ston These are "Dead Men's Fingers relatives of the sea-anemones and cora They are colonies of little polyps livi in branch-like structures, each bud bei the home of a polyp, the tentacles which protrude into the sea.

HOW CORAL IS FORMED

The corals are formed by simi polyps, not "coral-insects", as is som times stated (Fig. 36). They build u hard structure of calcareous matter, a as they increase, so they build up th great reefs and atolls, like gr community flats.

Another colony of little polyp-li marine animals, which, as it were, li in one great house or flat, is the spong If we cut through an ordinary ba sponge we see it is a gristly mass cross with channels. In pockets in the spon live the lowly animals, tentacles of whi keep a constant current of water passi through those channels, thus bringi in food and carrying out waste materi It must be mentioned, however, that t loofah of the bathroom is no relati to the sponge, for it is the dried gou of a cucumber-like plant from Egy Fig. 37 shows how a crab has made u of sponge as an effective camouflage.

When we speak of worms we do n necessarily always mean the comm

earthworm of the soil, which is merely one of a great group called the Vermes. This group is a kind of dumping ground for those animals that are not classified higher up. They include such "un-worm-like" creatures as the broad, flat liver-flukes that are parasites in the livers of sheep. They spend their early lives inside pond-snails, and these infect the damp grass of sheep pastures and in turn infect sheep. The leeches are also included in the Vermes, but not the so-called wire-worm—for this is the grub of the click-beetle—nor the glow-worm, which as we have seen is another beetle.

In Britain alone there are fifteen earthworms but none of these grow to such a size as the *Megascolides*, the giant earthworms of Australia, that attain a length of 11 ft. In our well-manured land there may be from 500,000 to 1,000,000 earthworms to the acre, and in poorer soil there may only be about 300,000.

The common earthworms live in burrows, coming forth at night to collect dead leaves, which they drag below for their food (Fig. 38). On each segment of a worm is a pair of setæ or bristle-hairs. When the worm moves through the soil it expands the forepart of its body, grips the soil with the setæ and then draws up the hind part of the body. Releasing the setæ gripping the soil at the front, it grips the soil at the rear and moves forward again.

CUTTING A WORM IN TWO

An old gardening belief is that if you cut a worm into two, two new worms grow. This is not quite correct, but that part with the head end—the nerve ganglia, corresponding to the brain in the higher animals—will grow a new tail. Likewise, the old belief that each arm pulled off a starfish will grow a new starfish is not true unless the torn limb has a portion of the central nerve ganglia.

Fig. 37. Some crabs use a sponge as camouflage, for their enemies avoid sponges in any form. (Above) the crab itself, (below) how it looks when it is clothed in the sponge.

On the seashore we find the ragworm, much in demand by anglers who dig them out of the sand for bait. It gets its name from the bunches of rag-like red growths down its sides, which are really its external gills. There is also the serpula worm that builds calcareous tubes on old oyster shells, inhabiting them for security during low tide but emerging to feed at high water.

The eel-worms, which belong to the

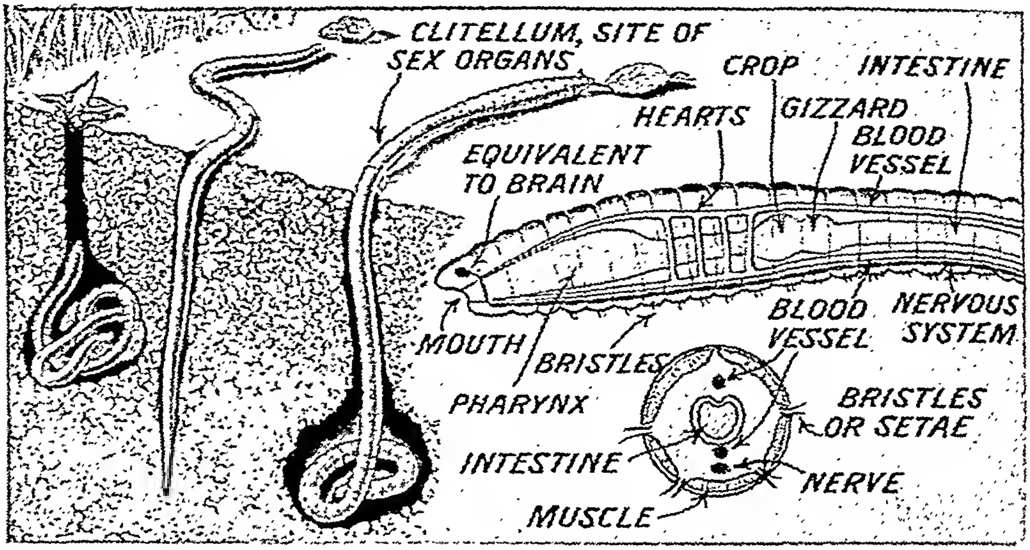


Fig. 38. (1) Common earthworm in its burrow with the entrance closed by leaves and stones; (2) eating its way through the soil ; (3) sweeping the ground for food with half its body still in the burrow for protection. On the right : longitudinal section (top) and cross section (bottom) of worm, showing details of anatomy. Earthworms have the characteristics of both sexes.

trematodes, are smaller and often destructive worms; like the pearl-worm, they are parasites.

Even more destructive to civilisation are the tapeworms, which are parasites in Man and in some animals, such as the dog. They grow to an enormous length. If we considered all the lowly animal forms that inhabit Man's body we should find that most of us are but walking zoos. A dozen different worms probably find a home in our intestines, and so do many lower animals, particularly the single-celled protozoa, such as the simple *amœba*, simplest of all creatures in the animal kingdom.

THE TAPEWORM'S LIFE

Taenia solium and *Taenia saginata* are two common tapeworms in Man's intestine, living on the food there and growing by budding off more tapeworms. They are furnished with a rig of twenty to thirty hooks or suckers, to prevent them being swept away from the stomach-wall by the passage of food. Specimens quite commonly measure two or three yards in length but, of course, they are much curled up inside us. There are very few of us who are without a few of these parasites in our intestines! Every day such a tapeworm will cast off fourteen segments, each containing at least 8,800 eggs, so that one of them will produce 80,000,000 eggs a year. Their life history is usually completed in the ground and browsing animals.

We have seen how mites and ticks and fleas have become flattened to live as "outside", or ecto-, parasites on the skins of other animals; and how tapeworms and liver-flukes have become lengthened or flattened to live as "inside", or endo-parasites in the bodies of animals. These changes or adaptions are surprising, but it is in the lowest of all animals, the single-celled Protozoa—inhabitants of our drinking water, of ponds and of the sea—that surprise us most of all. *Amœba*, simplest of all, is an animal that can "live for ever", for normally there is no natural death with *amœbæ*. As we have seen, it is just

single cell—a blob of protoplasm
ing matter, having a nucleus of
l control, the origin of the nervous
ı. Its *contractile vacuole* con-
ly swells as it fills with waste food,
hen bursts as it expels it. To
, *amœba* merely stretches out a
of protoplasm in one direction,
ıe rest of its body "flows" after it.
ed, it merely engulfs its food and
ɔs it into a vacuole. To grow or
luce, it merely divides into two,
ıucleus splitting first and the
plasm then separating round the
alves so forming two new *amœbæ*.

ŒBA—ANIMAL OR PLANT?

fact, so simple is the *amœba* of the
l kingdom that some of its relatives
aimed by botanists, who call them
t-animals"! The slime fungi, or
ɔzoa, that cover damp logs, are one
ɔle. As with the true fungi, if
haunts dry up, their spores germi-
to produce a mass of *amœba*-like
plasm that feeds and divides like
mœbæ of the ponds. The white
-corpuscles in our bodies are also
ımœbæ in their ways.

ıœbæ belong to the *Rhizopods*, or
-celled animals, having unstable
·shapes. On the other hand, the
ıinifera of the sea have tiny oval
that are the size of a grain of
To a certain extent they resemble
ing of sausages with about five
ənts, from which protrude their
ɔpodia, or foot-like branches of
plasm.

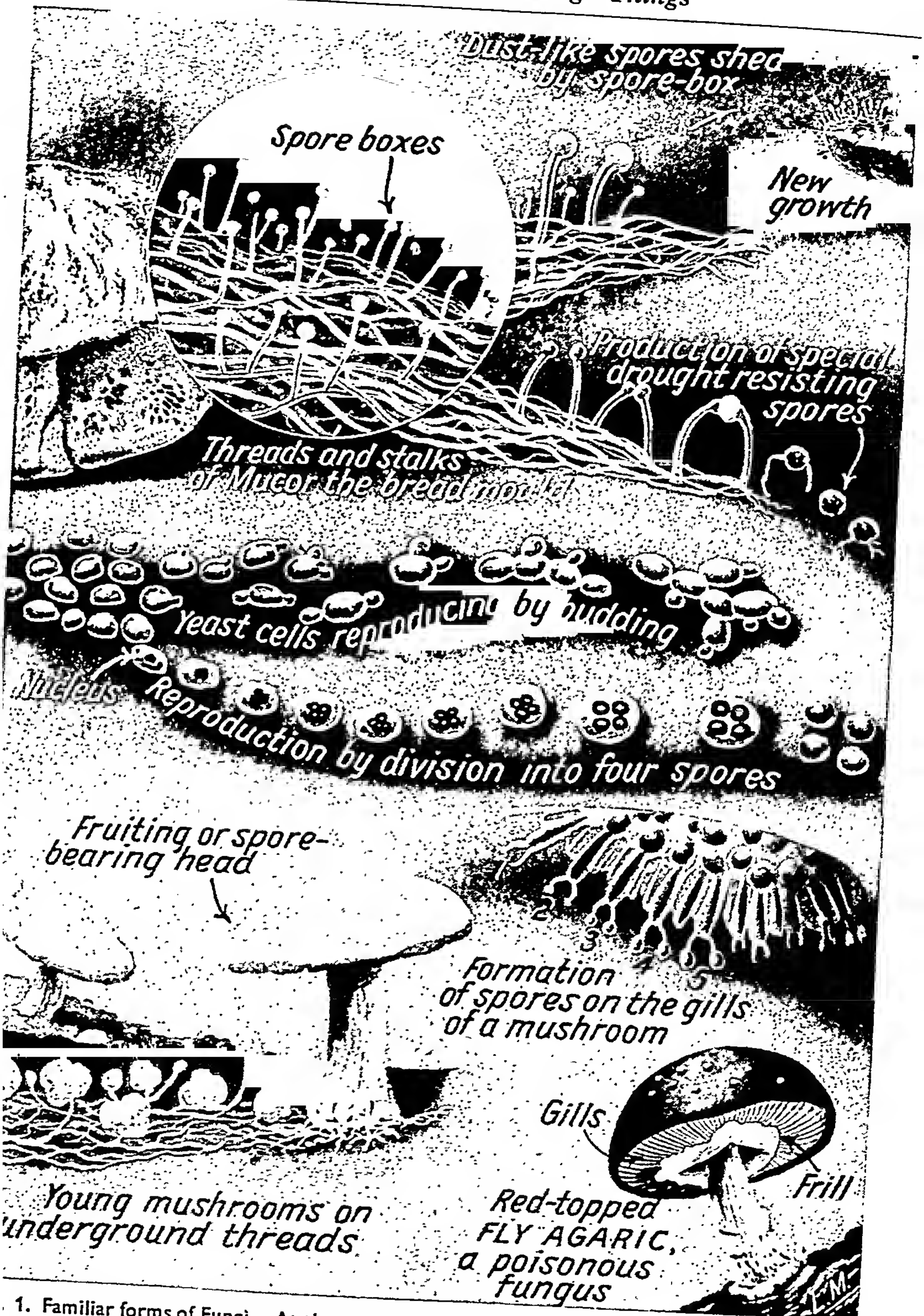
fresh-water there is the egg-shaped
ia having similar characteristics, while our chalk cliffs consist of masses of the seven lobated shells of *Globigerina*, another Rhizopod, that lived in the primeval seas. The countless shells dropped to the ocean floor when the Earth was cooling and the land masses forming, and so built up the Downs and other chalk hills.

The Radiolarians have beautiful flinty skeletons shaped in marvellous trellis-like forms and other intricate patterns.

In addition to the Rhizopods, there is another group of single-celled animals we call the *Infusoria*. They have more or less stable shapes and can be quickly bred from an infusion of hay in water. It is these creatures that cause the water of aquaria to turn thick and cloudy, for they subsist on dead and decaying vegetation.

Flagellates have small, whip-like appendages by which they travel through the water. One of the more fascinating members is *Noctiluca*, a minute kidney-shaped animal with a tail rising from the centre. It is this creature that causes the phosphorescent glow on the sea when it swarms in myriads.

Some other infusiorians have even more minute tails, hair-like cilia, or mobile feet surrounding their bodies and rotating to move them and also sweep in food. These include the little slipper-animalcule, or paramecium, easily bred from an infusion of hay. *Vorticella*, is another lovely animalcule resembling a little bell that grows on a stalk attached to pondweed. The bell is not hollow, but is filled with protoplasm and surrounded by cilia. This animal is, therefore, in fact, single-celled or unicellular.



1. Familiar forms of Fungi. At the top is shown the formation of mucor, the common mould seen on stale bread. Below is shown how yeast cells reproduce themselves. At the bottom (left) is shown how a mushroom grows and on the right is the Fly Agaric.

CHAPTER 20

THE PLANT WORLD

BOTANY is not generally regarded as a very fascinating subject by most people, but it becomes more interesting when we find that it includes a study of such every-day things as the bacteria that cause disease, the yeast that makes the dough "rise" when baking bread, and the moulds in Gorgonzola cheese. All these are plants, although they lack the leaves and flowers of the more familiar herbs. The mysteries and marvels of plant life include the methods by which plants can manufacture their food from the raw materials of the Earth and atmosphere, and how they can build up simple chemicals into complex substances. We must remember, too, that the subject is more particularly important because animals must ultimately obtain their food from some plant source, for even the flesh-eaters feed on animals that graze on the vegetation—for example, deer and rabbits, and insects—are reared on plants.

Plants are not always of the kind we associate with a garden or hedgerow. As in the case of bacteria and moulds, there are many plants—such as ferns, mosses, and mushrooms—that have no flowers because they never developed high in the evolution of plant life. Then again, there are others, like the seaweeds, that have no roots.

Some people think of plants as stationary things fixed into the ground by their roots. This is not true of all plants, for the dodder is a parasite that by means of suckers climbs up the clover in our fields. It may not touch the ground at all, for it extracts the juices from the other plants.

In ponds and streams there are marvellous microscopic one-celled plants, called Diatoms (Fig. 2) that are related to the algae or seaweeds and the green slimes in standing water. Their cases are so curiously and beautifully chased that microscopists collect them by the hundred and use them as test objects for their lenses. Although they are plants they move about as freely as little animals in the water. Two very common diatoms that any microscope will reveal to you are the ribbed diatom and the sieve-disc, the former with rib-like marks and the latter dotted or beaded so that it resembles a sieve. Allied to these are some further single-celled floating fresh-water plants called Desmids. They have the cells curiously divided almost into two, the two halves being joined

Fig. 2. A photomicrograph of Diatoms—tiny one-celled plants related to the sea-weeds.

by a narrow isthmus. Some are adorned with spines to preserve them from being eaten by aquatic larvae, such as wheel-animalcules or rotifers.

Amongst the most fascinating flora in the world are those of the human intestine, and these have important effects on our health. They are the various bacteria that wax and wane according to acidity and other conditions, and so medical specialists make a close study of them. Agricultural scientists know that the bacterial flora of the soil is equally important, for it has an effect on the nitrogen content of the soil so useful to larger plant life. If the protozoa, or one-celled animals, of the soil become too numerous they feed on the bacteria and alter the nitrogen content, and soil sterilisation has to be carried out to check the activities of the protozoa.

There are also bacteria that turn milk sour; give the flavour to cheese; and turn meat and fish "bad". Under the microscope they all resemble very minute fungi—mere specks of plant life. The larger fungi (Fig. 1) range from the familiar moulds on old walls and stale bread, to mushrooms and toadstools, and the delicious truffles of the deep oak and beech forests.

MUSHROOMS AND TOADSTOOLS

Many people do not know the difference between a mushroom and a toadstool. Of course, the botanist does not use such terms, except that he may say broadly that a toadstool is poisonous and that a mushroom is edible. The majority of the 500-odd species of fungi to be found in any parish are not poisonous, however. It is fairly safe to say that most of the poisonous toadstools have a little ring or frill around the stem, like the red-topped fly agaric of the fir woods.

What we collect as mushrooms are really but the fruiting or spore-bearing heads of the plant, for the plant proper consists of a mass of minute threads, or *hyphae*, that ramify through the damp ground below. When ready to fruit they send up their spores on a stalk, so that they will be held high and dry where they can be shed and do this so fast that a mushroom appears in a night.

The science of moulds and fungi, known as Mycology, is playing an increasingly important part in economic biology. The Imperial Mycological Institute at Kew was founded in 1920 to identify and describe specimens of fungi sent in by field-workers from all over the Empire. Where necessary the Institute advises on control-methods and acts as a clearing-house for information relating to plant-diseases.

Fungi or moulds are of great economic importance. One of them is the cause of "thrush", a disease that affects children's throats; others cause mildews or plant-diseases. The thick white mould on bread (*mucor*) consists of interwoven branches (*hyphae*) that are but branching tubes of protoplasm. They are living matter, absorbing their nourishment from the starch and gluten in the bread, while their spore-boxes, borne aloft, are black heads on tiny stalks. These burst and allow the dust-like spores to infect more bread when dampness prevails. But the green bread mould, or *Penicillium*, prefers drier conditions and generally grows on jam, cheese, and old boots. Its spore-boxes differ from those of the white bread-mould for they are bead-like strings of spores instead of a ball.

Staggering figures have been produced showing how insects, rats and sparrows cause millions of pounds damage every year, but fungi can take an equal share of blame for holding up Man's work. In 1916, a form of fungus known as black-rust disease destroyed

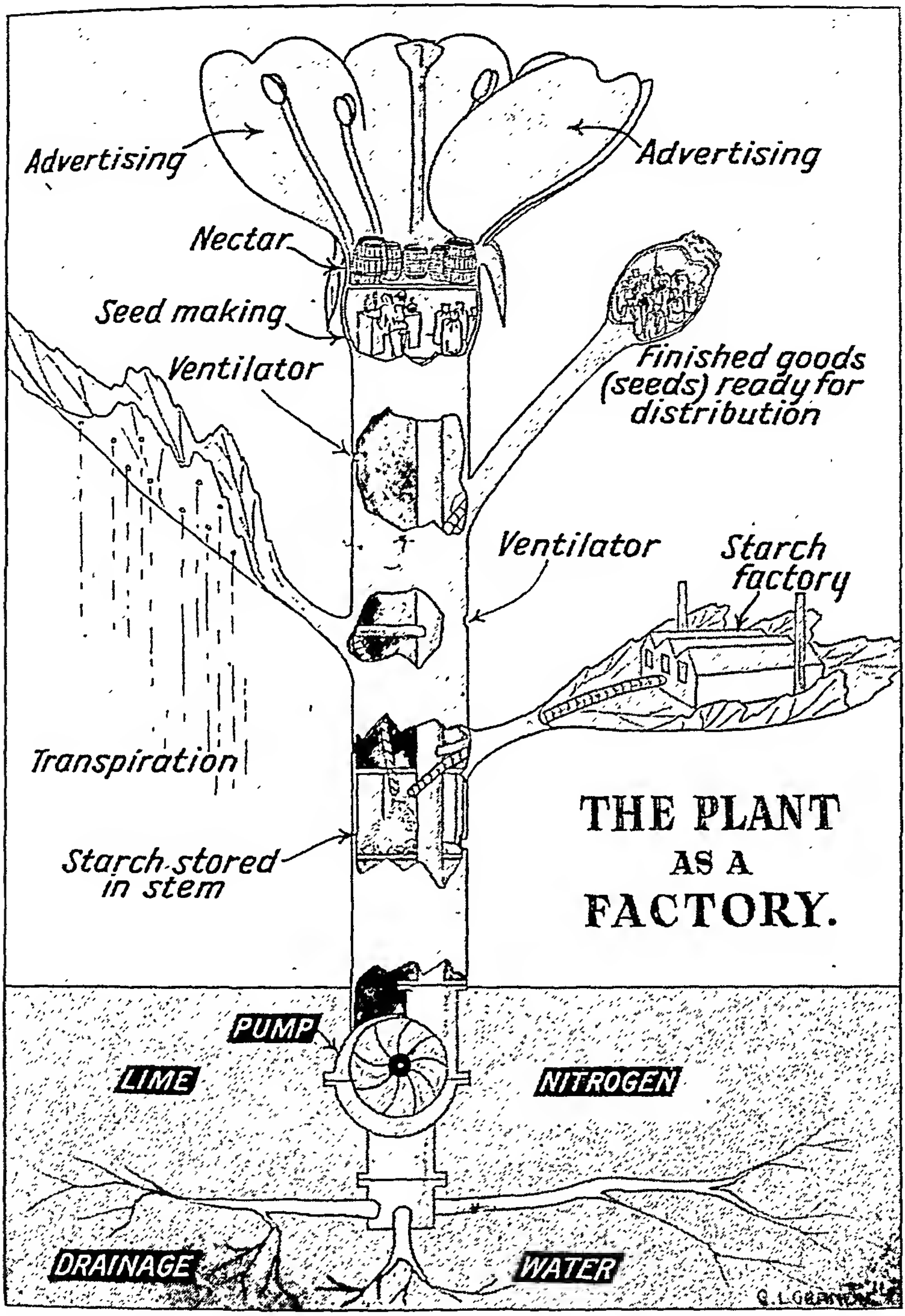


Fig. 3. The working of a plant can be likened to a well-run factory. Water, lime and nitrogen are pumped up by the roots. Starch is manufactured by the leaves and stored in the stem. Further up, the seeds are manufactured and stored in the pods. The flower is the advertising department.

£35,000,000 of wheat in three Prairie provinces. Black rust causes losses that average £5,000,000 a year in Canada alone. Another fungus, smut, costs Ontario over one million pounds a year. Australia loses fifteen per cent. of its annual output of animal and vegetable products through fungus disease. In 1924-5 New Zealand lost over £2,000,000 worth of root crops and cereals. When coffee-leaf disease appeared in Ceylon in 1868 it cost the island £15,000,000 and led to the abandonment of coffee production. Panama disease, which appeared in bananas in 1906, has caused the abandonment of thousands of acres of banana plantations in Central America. It has now spread to Jamaica, despite that thousands of pounds have been spent on research for a means of control.

SOME USES OF FUNGI

A recent book on Indian fungi enumerated 2,400 species, but this was stated to be probably only one tenth the number of fungi in India.

Fungi are used in the war on insect pests. In addition to the fungus *Empusa*, which kills house-flies, there is *Entomophthora*, which kills cabbage butterflies by gradually covering them in a white mould, and *Lamia* that attacks mosquitoes. The *Cordyceps* fungus of the tropics, which attacks caterpillars, entirely fills the body of the caterpillars with mould. When ready to fruit or bear spores, it produces a stalk one foot long, with the spore-case on the top. These fungi have club-shaped fruiting bodies, brightly coloured, and in some species they attain a length of 29, or more, inches.

If you have kept goldfish or other aquarium animals you have probably noticed fish with small, mouldy growths appearing on the head. These are due to the troublesome aquatic fungi that kill fishes. Many fungi live in water and at sewage farm filter beds certain fungi thrive on the nitrogen there, as do certain *algae* or slimes. These encourage a high population of gnat larvae, moth-fly grubs, and earthworms, which in turn attract a rich variety of waders—gulls and other birds-of-passage—explaining why a sewage farm is such a favourite haunt of the bird-watcher looking for his *rara avis*.

Yeast is a minute fungus consisting of small nucleated cells about eight-thousandths of a millimetre in diameter. Under warm conditions these cells increase rapidly by budding—hence the rise of the dough. They help to transform the sugar in alcohol for the fermentation. Yeast cannot store starch as so many plants can, but like some other fungi it can store food as glycogen or fat, much in the same way that animals store food in their livers.

There is another marvel about yeast that earns it the description of *anaerobic*—it can live in a sugar solution without oxygen. It decomposes the sugar into carbon dioxide, water, and alcohol, and—as in ordinary respiration—this liberates energy in the form of heat. Hence the rise of temperature in fermentation that thus takes the place of the respiration of higher creatures.

Although plants breathe, they do not do so quite in the same way as animals. They have breathing pores (*stomata*) on the under surfaces of their leaves and on the stem (*lenticels*). If we immerse a twig in hot water to force out the air, we see it leave by these pores. Indeed, we can liken the structure of the higher plant to a factory working in the sunshine (Fig. 3). The leaves manufacture starches and sugars from the carbon dioxide in the air, with the aid of the green colouring matter of chlorophyll and the sunshine. As they do not need the oxygen in the air for this

work, they give it back, hence the health-value of plants in the light.

Starch of course is not soluble enough for the plant to transport its manufactures from the leaf-factory to its storage quarters in stems—like celery and rhubarb; in roots—like carrots; in leaf-bases—like onions and other bulbs; in root-bases—like crocuses and other corms; or in tubers on the roots—like potatoes. Because of this a plant transports these manufactures as sugars in solution and then turns them into starch to store them.

In autumn, when winter is approaching and there is little sunshine for this *photosynthesis* or "leaf-work", the plant begins to extract the valuable chemicals from the leaves. These then gradually change colour and so are produced the beautiful tints of autumn, until finally the plant forms layers of cork-like material between the leaf stalk and the stem. The rain collecting here freezes and—as in the case of the burst water-pipe at home—forces the cork apart. The next breeze blows down the weakened leaf, bringing about the autumnal "fall of the leaf".

FUNCTION OF PLANT ROOTS

The roots of the plant may be likened to a great pump forcing water up the stem at such pressure that the plant is held erect (Fig. 3). When this pressure is lessened in drought, the plant wilts. Some big plants—such as shrubs and trees—require even greater support and they reinforce their cells with an extra supply of cellulose or woody tissue. Others, without woody stems, attain great heights by climbing up stronger plants. Thus the ivy climbs the tree trunk or wall by adhesive roots produced from its stem. The bryony, and its relative the garden cucumber, climb by hooking their leaf-stalks around their host. Wild roses and brambles scramble up by little hooks. Runner beans and peas have little sensitive tendrils that twine around whatever they touch.

Mention of the rose reminds us that this plant has not true thorns, for what we call thorns are really prickly growths of the skin. A true thorn, as on the hawthorn, is a miniature branch, and if we cut it through we see it is an outgrowth of the stem proper, not just the cuticle. Incidentally, there are many other botanical misnomers in everyday speech. The strawberry is not a berry; nor are the fruits of the mountain-ash or rowan, nor those of the sloe or blackthorn,—they are *pomes* and are related to the apples. The blackberry is really a collection of little berries or *drupelets*—the fruit being the form in which the ripe seeds are presented, so that it usually has many seeds. The date is a single-seeded berry; oranges and lemons are large berries; and bananas are berries that under cultivation no longer produce seeds.

The flower is the advertising department of the plant (Fig. 3). Its prettily coloured petals and sweet scent take the place of placards and advertisements to attract customers—in this case, insects—to fertilise the sexual organs of the flower. They do this by getting covered with the powdery pollen from the *anthers*—or male sexual organs—and distributing it to the *stigma*—or female organ—of other plants, thus avoiding cross-fertilisation.

The lines we see on some flowers, such as nasturtiums, are *guide-lines* to show the insect the way down to the nectary—the wine-cellar where the guests are entertained with free drinks so that they will come again! Primroses are believed to be fertilised by only one insect, a bright brown fluffy fly, the "Primrose Sprite". Where nectaries are deep only the long-

tongued insects, like bees, can reach them, for their hairy bodies are most useful in distributing the pollen.

Some flowers, like snapdragons, take a precaution to prevent "gate-crashers" (as ants and flies) from stealing the nectar without doing the work of fertilisation. They have a lip that can only be weighed down by a heavy insect such as a bee. Other plants may have hairy stems to prevent them being climbed and robbed by ants. The foxglove has little teeth to bar their way into the flower. The mountain gentian has a large flat top to the stigma, blocking the entrance to the corolla and this must be forced aside.

SELF-FERTILISATION OF PLANTS

Plants adopt all kinds of devices to avoid self-fertilisation, for this weakens the plant. In the primrose we see two distinct types of flower. One, the "thrum-eyed", has the stigma half-way down the corolla or flower tube, and the anthers around the top. The other, the "pin-eye" has the stigma reaching to the top of the corolla, but the anthers are half-way down. When a bee visits a thrum-eyed flower and inserts its long tongue to reach the nectar-glands at the base of the petals, its hairy body rubs against the anthers at the top and becomes covered with pollen; but the stigma is too short and low down for its body to touch and fertilise with that pollen. When it reaches a pin-eyed flower, its body rubs against the tall stigma first and thus gives it some of the pollen from the other plant. The fore-part of its body, lower down, comes into contact with the short anthers and is covered with their pollen so that when next it visits a thrum-eyed flower, its head, low down in the tube, rubs against the short stigma and gives it the pollen from the pin-eyed flower.

There are many other contrivances in nature to secure the desired end. For instance, the arum, or cuckoo-pint, of the hedgerows traps visiting insects in the lower part of its spathe and does not release them until the organs are ripe for fertilisation. Another arrangement to avoid self-fertilisation is the fact that the anthers and stigmas of many flowers ripen at different times.

The orchids have a fascinating method that we can demonstrate by inserting a sharp pencil-point into the orchid flower. When you withdraw the pencil you see an anther stuck on to the end, and if you watch this, it gradually bends forward from the vertical to a horizontal position. That is exactly what happens when the bee's head takes the place of the pencil. An anther is fixed to the bee's head and slowly bends forwards along the head so that it is not knocked off in flight. At the next orchid the bee visits, the anther is in a suitable position to fertilise the flower.

Some plants—such as the grasses and the rushes—have very simple flowers. They have no pretty petals but consist only of a folding of bracts, or leaflets, over the sexual organs. These plants rely on the wind to distribute their pollen and thus require no advertising devices to attract insects. In summer, when the grasses ripen, their flowering heads bend over to protect them from being eaten up completely by cattle.

HOW FERN-SPORES GERMINATE

The ferns are a group of non-flowering plants—even the so-called "flowering fern", or *Osmunda*, of the garden has no true flowers; instead it has a stalk of rusty-brown spores that are even more primitive than seeds. The brown rings and lines under the fronds of ferns are the spore-boxes and the dust-like spores, shed in dry weather, germinate in damp, humid, conditions. These do not develop into young ferns, but

into curious little green "*prothalli*", resembling tiny, single-celled layers of tissue. This produces root-hairs on the under surface and little knob-like sexual organs that produce numbers of *antheridia*, very primitive forms of pollen. The *antheridia* travel through the moist film around the prothallus and in reaching the female sexual organs, or *archegonia*, fertilise them, causing the growth of the young fern.

Like the insect-egg, the fern-spore is not rich enough in material to produce a replica of the adult at once. It can only produce a kind of half-stage that must imbibe further food .before the adult stage can be completed.

The reproduction of the mosses and fungi is even more primitive, so now we can understand why botanists group the plant world into the flowering and flowerless plants.

PLANTS THAT LIVE ON INSECTS

There are carnivorous plants that catch insects for food. Amongst these are the sundews of our heaths and bogs, with sticky-leaved traps like flypapers. Other similar plants include the American pitcher plant, Venus's fly-trap, and the little bladderwort that has an ingenious arrangement like a box mouse-trap. Other plants, such as the bird's-nest orchid, feed on the roots of the dwarf willow. The fleshy broom-rape of the rye fields, and the toothwort of the hazel woods, are parasites. They feed on other plants and therefore require no leaves to manufacture their food.

A first-class mystery is the marvellous way in which the tap-root of a growing seed will always grow downwards, whilst the new shoot grows upwards, no matter in what position we plant a seed. If we invert a seed after it has commenced to grow the root will still turn downwards and the shoot upwards, resulting in a corkscrew-like twisting.

Most plants grow towards the light, as we can easily see from the foliage of pot-plants that stand in the window. An exception to the general rule is the little purple ivy-leaved toadflax of our country walls. It suddenly changes its ways just before its seeds are ripe and its shoots, instead of growing towards the light, seek the dark cracks between the stones. They grow into these cracks and shed their seeds where they are intended to grow next year.

A walk with a naturalist round a garden reveals many other marvels of the plant world that most gardeners overlook in their digging and planting. Here, for instance, is a remarkable fact. The poppy may shed more than 6,000 seeds over a square foot of ground, and they will all germinate simultaneously. The sunrose also sheds its seeds all at the same time, but it will eventually show three different stages of seedlings with a two months' interval between the germination of some of the seeds. The reason for this is that if all the sunrose seeds began to grow in early spring, late frosts would kill them off. By delaying the growth of some seeds this risk is avoided.

The famous ever-recurring stories of "mummy wheat" said to be grown from grain found in the tombs of Ancient Egypt and said to have been placed there by the Pharaohs thousands of years ago, are not supported by the facts. Whilst the maximum period of fertility of some seeds is between 300 and 400 years, that of wheat cannot remain dormant for more than 25 years. The wheat-grains found in the Ancient Egyptian tombs must have been stored there recently by native farmers, or others who had access to the tombs. Authentic wheat of ancient origin found in the tombs has in each case had the tissues so disintegrated as to make germination impossible. The record

for longevity is held by a seed of *Nelumbo nucifera* obtained in a peat bed of from 120 to 400 years old, and germinated at Kew in 1932. With most garden plants, however, the rate of germination drops rapidly after the seeds are seven years old.

Further marvels are revealed when our plants commence to grow. Some of them exhibit enormous strength in the process. Coltsfoot has forced its way through macadam and asphalt paving. Agaric fungi have forced a path through hard tennis courts laid over former rubbish tips, the humid conditions of which breed such fungi in abundance.

The structure of most plants is adapted to their requirements. The lily-of-the-valley, which often has to grow through hard soil, has spear-like tips to its shoots enabling it to pierce through the soil more easily. The microscope reveals how the tips of daffodil leaves are reinforced with hard cuticle, enabling them also to force a passage through the soil—we see here a link with the animal world, for it is with exactly the same idea that a chick's beak is reinforced at the tip with a hard enamel "tooth" to enable its owner to force its way out of the egg-shell.

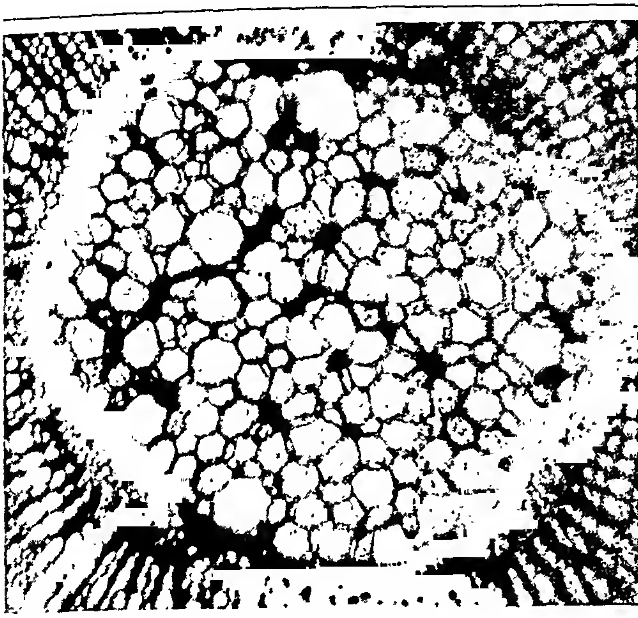
Not all plants are thus reinforced, however, for the shoots of winter aconite have but tender tips. But they are always bent when pushing their way through the soil, and thus any damage to the tips is obviated. Once they reach the light they straighten out. Peas come through the soil in a like manner, but maize has straight shoots with armoured tips. Experimenting in this connection, Professor Salisbury, of the British Empire Naturalists' Association, took growing pea and maize shoots while still under the soil. He straightened the former and bent the latter, with the result that they failed to force their way through the soil.

Why does fool's parsley grow to two or three feet tall when a garden weed, but only to six inches when in the cornfields? It is a case of natural selection, for fool's parsley sheds its seeds late in the summer. If it grew so tall in the farm fields it would be cut down with the harvest. Indeed, all the tall plants have been "weeded out" of the harvest fields and only those small varieties are left to grow up and produce seeds that inherit this tendency towards smallness. By mowing our lawns regularly we encourage a glaring example of artificial selection, for in a similar way we encourage such weeds as daisies, plantain, thistle, dandelion, etc. to grow in a flat rosette of leaves so to escape destruction by the mower, instead of in the more upright foliage of the open country. On a certain close-cut lawn 105 rosette plants were counted compared with only 31 on a similar area where the grass was allowed to grow.

CREATING NEW PLANTS

In Russia, when certain vetches were troublesome weeds in the cornfields, sieves were used of such a size as to allow only the seeds of the corn to pass through, the larger vetch seeds being withheld. After some years, however, a new, small-seeded race of vetches began to increase in the fields. It was found that the sieves had allowed passage to any unusually small seeds of the vetches. Growing up as the only vetches in the fields, these had inherited a tendency to small-seededness. Any large seeds these produced failed to pass through the sieves, and eventually a new small-seeded race of vetches sprang up.

This brings us to the mystery of how new plants are created. We know that gardeners can produce new varieties of daffodils and roses by fertilising plants with pollen from selected types. They can produce them also by grafting—



A microphotograph showing cross section of a plant's stem.

that, is inserting a cut portion of woody stem into another stock, the wound so caused healing if bound with damp moss and raffia. Although we grow over 2,000 different rhododendrons and over 5,000 daffodils, these are mostly only varieties of the same species. Thus, cross-fertilisation is easy if the gardener produces the correct growing conditions. But to create entirely new species of plant, which are not sterile like most hybrids but will produce their own fertile seeds, is one of the wonders of modern botany. Strange to say this discovery was due to an accident.

When we considered the wonders of heredity we mentioned that inside the nucleus of the germ cells there were certain rod-like structures called chromosomes. These are always evenly paired with two of each kind, and they contain the genes or factors of inheritance. In normal reproduction the cell divides, half the chromosomes going into one sexual cell and the other half—all similar to the first group—going into the other division. Thus, when fertilisation takes place by the fusion of two germ cells from different specimens of the same species, the chromosomes pair together again, like with like. But if the gardener or the animal breeder crosses two different species, their chromosomes cannot unite into pairs because they are not alike. Because of this a "hybrid" is infertile, or sterile as it is called, for it cannot produce germ-cells.

The ordinary *Primula Kewensis*, so popular in our greenhouses, was a normal hybrid produced at Kew by crossing two primroses, *P. floribunda* from the Himalayas with *P. verticillata* from Arabia. The hybrid received nine chromosomes from each parent plant; but as these were not alike, coming from different parents, they would not pair and the hybrid was sterile. Although it could not produce its own seeds the plant, of course, could be increased by shoots or cuttings (vegetative reproduction) like most plant hybrids, and many cuttings were taken. Suddenly, to the astonishment of botanists, however, a plant of *Primula Kewensis* began to produce seeds! Now that it was fertile, it was no longer a hybrid, but a new species.

How had this mysterious plant come into being?

In growth, a plant cell divides into two, nucleus included. It appears that the cells of a branch of the plant, in trying to carry out normal growth or reproduction, split each nucleus into two, and in this division the chromosomes split also. The complete cells failed to divide, however, so that instead

of the original nine chromosomes from one parent and nine chromosomes from the other parent plant, it had eighteen split chromosomes from A and eighteen from B. These were all contained within the one cell—an even number, with two of each kind, giving exactly the conditions necessary for reproduction. Pairing now took place between the chromosomes, increased by this splitting, and the plant became fertile. Dividing again, the chromosomes produced sex cells, each with eighteen chromosomes (nine from A and nine from B) instead of the original hybrid cells with only nine chromosomes (one group of nine from A and the other cell's nine from B). Thus the new cells could pair evenly, like normal species. In other words, the mystery of creating a new species had been solved by doubling the chromosomes.

DOUBLING THE CHROMOSOMES

In a similar way, this doubling of the chromosomes has occurred naturally in the wild, creating a new plant—*Spartina Townsendii*, or Townsend's cordgrass, now widely grown on sandy shores to keep back the erosion of the sea. About 1860 the American *S. stricta* appeared in Southampton Water, probably being brought over in the water-ballast tanks of ships—by which means many alien plants are introduced. This grass eventually crossed with the native *S. alterniflora* and produced an infertile hybrid. Suddenly, the doubling of the chromosomes made it fertile, and so the hybrid became a new species—*Spartina Townsendii*, now widely planted on the coasts of Norfolk, Lancashire, New Zealand, Normandy and the Zuider Zee.

The zoologist has learned to take a hand in the creation of new species of animals by using X-rays to split the chromosomes of the cells of banana-flies. This treatment causes them to break up and join together in another structure, the hope being that there will be a sufficient likeness to enable pairing to be carried out and new species created. So too, has the botanist learned to effect this "doubling of the chromosomes" to create new plant species out of old hybrids. Professor Kostoff of Moscow has shown how the doubling of chromosomes in *Nicotiana* (the tobacco-plant), *Triticum* (wheat), and *Lactuca* (lettuce) can be obtained by soaking the seeds for two days in a supersaturated solution of acennapthene, with an excess of crystals.

Another mystery of plant life is the loss of scent in the famous musk plant. This was noticed by gardeners long before the war—with which some people associate it—but it is probably due to a reversion to the natural conditions of this North American plant. In the wild, scented species were the exception, but gardeners cultivated those plants with a strong musk scent to produce a strain that was popular.

Reversion to the original stock is a strong tendency with most cultivated or domesticated forms of life, and numerous examples may be seen around us. For instance, the yellow variety of privet hedge repeatedly sends out shoots like its common green ancestor. Many double garden flowers do not always come up true to seed, but grow odd single plants like those from which they originated. In cemeteries, where large cultivated daisies have been planted on graves and later have been neglected, we see how they spread into the surrounding grass. There they cross with the wild daisy and eventually, after some years, they are no different from their wild ancestors.

A plant stores its food as starch, and we can detect its presence by touching a potato—or a celery stem—with iodine, when it turns deep purplish blue, because

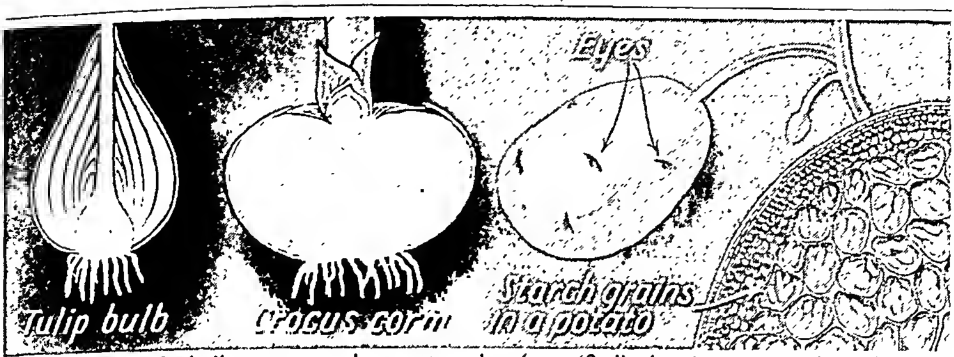


Fig. 4. Sections of a bulb, a corm, and a potato-tuber (magnified), showing structural peculiarities.

of the chemical action of iodine on starch. If we take a variegated leaf and test this for starch, we find that it is present only in the green part and not in the yellow, or wilted, part of the leaf. This is because the green colouring matter, or chlorophyll, is necessary for the manufacture of starch. If we cover a green leaf with a black wrapping, or stand a plant in a dark cupboard, or even cover part of the lawn with a box or mat, the green turns to yellow, for light is essential for the production of chlorophyll.

A plant turns its starch into sugar by the use of an enzyme (*diastase*). If we place a piece of bread, which is wheat starch, in our mouth, the saliva acts as an enzyme, and we find that the taste gradually sweetens as the starch is converted into sugar.

We can show that a plant gives off water vapour (*transpiration*) when it breathes, by inverting a bell-jar or glass jam-jar over a growing plant. After a time the glass becomes misty as the moisture from the plant condenses. A sunflower with 39 sq. ft. of foliage gives off 3 lb. of water in 24 hours; one with 19 sq. ft. gives off about the same amount in the same time, most transpiration taking place in hot or windy weather. To confirm that this result is genuine, we can set up another jar inverted over soil without a plant, and it will show none.

To show that a breathing plant gives off carbon dioxide, as does a breathing animal, we insert a lighted taper into a bell jar after it has stood some time over the plant in the dark. The light quickly goes out, for the air there lacks the oxygen necessary to support combustion of the flame. On the other hand we can show their health-giving value in daylight—when they give off oxygen during their photosynthesis, or leaf-factory work—by repeating this experiment in the sunlight. Then the flame should burn longer than usual under such conditions. We can show this also, by dropping some pond-weed into a glass trough of water, and inverting a glass funnel over it, and fixing a test-tube full of water to the end of the funnel tube. As the green pond-weed manufactures starch in the sunlight, it gives off oxygen. This rises through the funnel into the test tube, there replacing the water. In due course we shall have enough oxygen to test with a light, which will suddenly burn up as it uses up the oxygen.

To show how a seed grows by the rapid expansion of the tip of its root, we fasten a bean or pea to a piece of cork in water where it will soon grow by sending down its tap root. We mark this root with small marks or cuts, all an equal distance apart, and allow the bean to go on growing until twice its original length. When we look at the marks we see that they are still evenly

spaced at the base, but at the tip their spaces have increased enormously, showing where the bulk of the growth has taken place.

An interesting example of osmotic pressure—or the means by which plant tissue can imbibe solutions and become rigid—can be demonstrated by cutting a longtitudinal half stem of dandelion (in summer) or castor oil plant (in winter). This will immediately curve over towards the uncut side because of its weakness. If we stand it in ordinary water, the curvature is increased but if it is put into a salt solution, the plant straightens itself up again. A microscope will show how the root-hairs of the plant absorb water and become rigid by osmotic pressure. The process also can be demonstrated very forcibly with a pig's bladder. If this is filled with water and placed in a salt solution, it collapses through loss of its water outwards. If the bladder is filled with salt or sugar solution and placed in water, it absorbs so much water that it distends and becomes hard—in fact it may even burst.

When a plant has turned its leaf starch into sugar it transports that sugar (in solution) to the stem, or to some other store-place. This can be shown by putting a plant, and also a separate detached leaf, in a dark cup-board, where they cannot make any more starch owing to the lack of light. If we then test with iodine for the usual blue stain that shows starch, we find there is still starch in the cut leaf—for it had nowhere to transport it to—but none in a leaf attached to the plant, for the plant has taken the starch away.

To show that a plant produces heat by respiration, we need only insert the bulb of a clinical thermometer into a flower-head and keep it there awhile. If a second thermometer is suspended in the air nearby, we see that the average plant maintains a temperature of 2°C. above that of the surrounding atmos-phere.

The movements of plants in relation to light will show that a daisy, growing with wide open petals in the daylight and then suddenly placed in the dark, will close its petals by 30° in $1\frac{1}{4}$ hours. The clover or trefoil leaf closes likewise, for this is one of the plants with *nyctitropism*,—or "night-turning-in"—a regular movement the purpose of which is to protect the leaves from cold.

A series of remarkable experiments

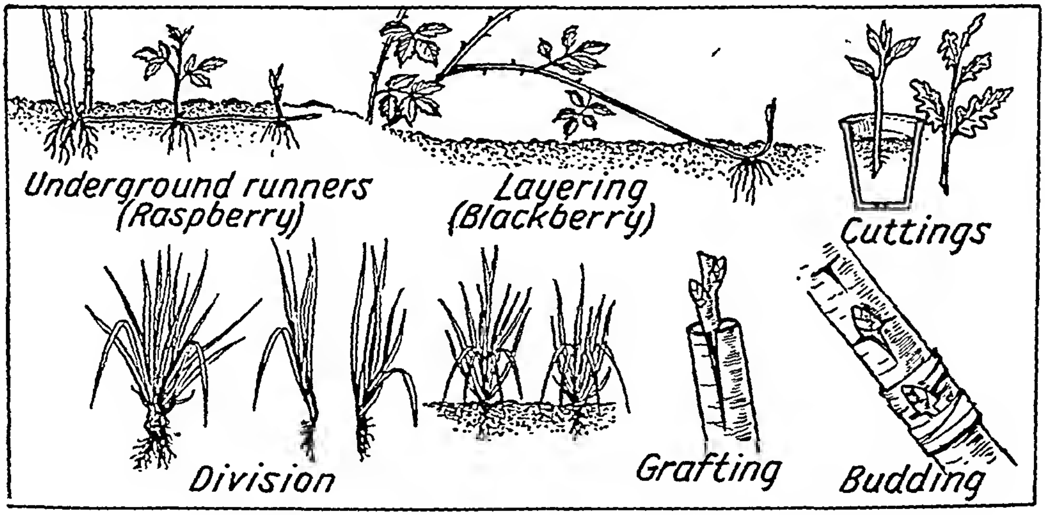


Fig. 5. Some of the ways—other than by seeding—in which plants can grow and multiply.

were said to show there are heart-beats in plants. When an American scientist (Dr. G. A. Persson) repeated these experiments he obtained contradictory results and claimed that the so-called heart-beats were due to mistaken observations. If they did exist the instruments used were not delicate enough to record them.

BULBS AND CORMS

How many people know the difference between a bulb and a corm? (Fig. 4). Take an onion—or a tulip, daffodil, or lily bulb—and a crocus corm, and cut each across. We see that a bulb is like a big bud with thick, fleshy leaves. The leaf-bases fold over the growing point and are thick with the starch stored in them, ready for the growth of the new plant from those roots arising from the tiny stem at the base. But the corm, like the crocus, is a thick stem-base, full of hard starch that is stored in the stem base and not in the leaves. Exactly as around the sides of an ordinary stem, there are visible the scars of the old leaves, and in their axils are the little buds of the new leaves. The fibrous, papery covering of the crocus corm consists of the dried, withered leaf-bases from the plant-stem before it stored its food there, as we can see if we pull them off. The potato is like a swollen stem —a swollen tuber of the tip—and the "eyes" we cut out are the growing points of the shoots it will send out for the new plant.

New plants can grow from many origins other than seeds (Fig. 5) The *Bryophyllum* of the greenhouse produces curious little bulbils around the edge of each leaf. These fall off, take root, and grow up into new plants. By vegetative reproduction the tissues of many plants can send out roots when they come into contact with the soil, and thus in the garden we can grow new plants from carnation and other cuttings, or new rhododendrons and other shrubs by "layering" their shoots.

The blackberry of the country lane sends out long trailers during summer, and by autumn these have grown to a length of 10 or 12 ft. away from the parent plant. The tip of the trailer, or runner, then turns down and buries itself in the ground, to grow up next year as a new plant. Incidentally, in Britain alone there are 116 species and 97 varieties of the common bramble; 240 species grow wild in France; and 4,000 named forms are found on the Continent, showing how variable is this plant. It is still in a state of active evolution, adapting itself to the various conditions it meets with in its efforts to colonise the countryside. In New Zealand, where a single blackberry "bush" is reputed to cover over 200 acres, it is a veritable pest.

VARIETIES OF THE PRIMROSE

The evening primrose, a North American plant of our gardens, which grows wild on many sandy places, is similarly in an active state of evolution. It produces many variations, and—as with *Primula Kewensis* and *Spartina Townsendii*—it has succeeded in producing a new species by doubling the chromosomes in a hybrid form. It is one of several night-flowering plants, others being certain cacti, tobacco plants, honeysuckle, convolvulus, etc. They are fertilised by night-flying moths, and are usually either white in colour or highly scented to attract these insects in the dark.

It is a curious fact that very few blue flowers possess scent. With the exception of the roses, most of the sweetest scented flowers are white.

Flowers do not open at the same time during the day. On a normal summer's day, when the daisy is open from sunrise

to sunset, the petals of the scarlet pimpernel are usually closed after noon. Goat's beard closes its petals about midday, and the water lily, opening about 7 a.m., will close about 5 p.m.

Another marvellous plant associating with a fungus is the lowly lichen, that small, colourful encrustation we see on rock or damp twigs. To these it is attached by a disc instead of roots. It obtains no food from the rock or wood on which it lives, but takes this from the moisture and dust in the atmosphere. When we examine the lichen we find it is actually the association of two plants—a fungus whose growth-threads, or *mycellia*, entwine around *algae* or single-celled aquatic plants. As we have seen, these are very simple relatives of the seaweeds and were amongst the first plants on the Earth.

Some plants—such as the garden butcher's-broom—have flattened branches to serve as leaves, whilst others have needle-like branches that act as leaves, as in asparagus. Some flowers, like the anemone, have no petals but their sepals are highly coloured and easily mistaken for petals. Others, again, like the grasses, have neither petals or sepals.

WHY A NETTLE STINGS

Have you ever wondered how a nettle stings and why, if you grip the leaf quickly and firmly, there is no sting? Its action is very similar to the stinging cells in the tentacles of the sea-anemone of the seashore, which is of course an animal, despite its name. It has a delicate, trigger-like coil in a cell, its sharp point suddenly being released on the slightest touch. The nettle-sting is developed from a single cell with the walls of the hair silicified, a small knob protecting the fine point until touched, when it breaks and allows the trigger to penetrate the skin.

The prickles of the holly bush like those on the thistle and the sting of the nettle, are to protect the plant from browsing animals. At the top of a tall holly tree, above the reach of browsing animals, it will be seen that the leaves are without prickles. Thus we see that plants, like animals, adapt their structure to their environment.

THE WATER CROWFOOT

In the ponds and streams we find the water-crowfoot, a small white buttercup with two kinds of leaves. The floating leaves at the surface are large, but under the surface are curious ribbon-like threads of leaves that offer no resistance to the currents but just flow out to their full length. Thus, the plant can grow in a stream without being swept away. For a similar reason, the sedges that stand in the stream have triangular or three-sided stems to cut through the moving water, just like the three-sided supports of the piers of a bridge that stand with their pointed edge to the current. On the other hand, the rushes that grow in the still waters of swamps and marshes have almost round stems.

Other puzzling plant structures are the curious nodules on the roots of many plants, such as peas and beans. These nodules are little chambers wherein bacteria are cultivated and preserved by the plant. The bacteria are very useful in enriching the nitrogen content of the soil so that the plant can use this to its own advantage.

Most berries are highly-coloured because it is not desirable for all the seeds of a plant to drop nearby, for they would grow up and choke the parent. They must be distributed, and berries and similar fruits are really a bait to the birds. Attracted by the colours, they eat and digest the pulpy covering to the seeds, while the latter pass through their intestines unharmed, to be dropped perhaps miles away

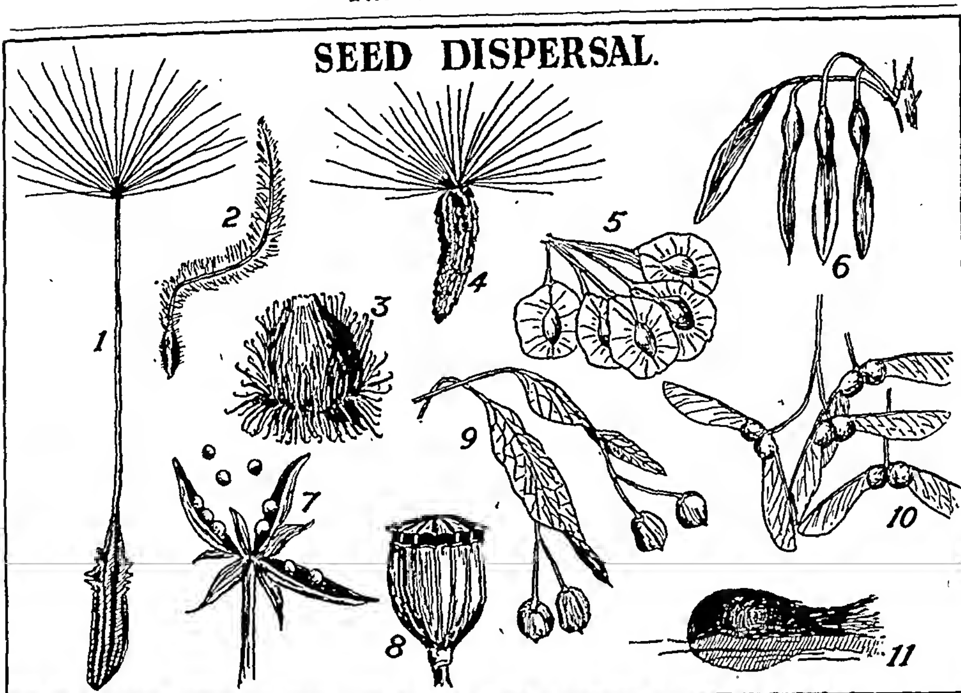


Fig. 6. Methods of seed-dispersal: (1) dandelion, (2) traveller's joy, (3) burdock, (4) sow thistle, (5) elm, (6) ash, (7) dog-violet, (8) poppy, (9) lime, (10) sycamore, (11) coco-nut.

whither the bird has flown. Most berries are red because red is the favourite colour of the great thrush tribe that feeds so much on such berries as hips and haws, yews, and hollies. Yellow and orange berries are the next most numerous, followed by black, white, blue, and finally by brown and rose-pink. Forty-three species of bird feed on the black, red, or yellow-orange fruits of the *Rosaceae* plants; 33 species on *Vaccinium* berries; 48 on berries of the Brambles (probably the largest number for any one plant group); 24 on crow-berries; and 14 on the holly.

Not all plants depend on birds for seed dispersal, and there are many other methods by which a plant achieves its object. Those seeds with hairy parachutes, such as the dandelion and sow thistle (1 and 4, Fig. 6) effect dispersal by the wind. Other plants have hooked seeds, like those of goose-grass, enchanter's nightshade and burdock (3, Fig. 6). These seeds cling to the hair of passing animals and drop off later. Other seeds float—like the coconut in its husk (11, Fig. 6)—drift on the water and may thus be taken by the currents to colonise some coral island or atoll. Some floating seeds—like those of the water-lily—are buoyant at first and remain so until they have floated well away from the parent colony, when they become water-logged.

SEEDS WITH WINGS

Other seeds have wings, and fly through the air to a considerable distance from the parent plant.

Some seeds are jerked out of the seed-box by mechanical means. The drying pods of the gorse and violet (7, Fig. 6) burst and fling—or "dehisce"—the small slippery seeds, exactly as we flick an orange pip into the fire. The poppy-head is full of minute seeds that like pepper from a pepper-pot are

jerked out through the pores each time it sways in the wind (Fig. 6).

Seeds are carried about in the most unlikely ways. Mud collected from the feet of birds has been planted in sterilised soil to prove that seeds are transported in this manner. In the "turn-ups" of a man's trousers after he had walked across a common, were found 110 seeds of grasses and two other plants that he had unknowingly gathered in his walk. Seeds contained in an ounce of dust swept from a church pew and placed in sterilised soil grew fourteen plants. A ball of earth taken from the foot of a partridge and kept unbroken for three years produced 82 plants when watered. The crop of a Cheshire wild duck was found to contain 400 seeds of cleavers or goosegrass; that of a Lancashire wood-pigeon, 986 rye-grass, 561 barley, and 108 clover seeds.

THE FOXGLOVE FLOWER

The flower of the foxglove is lined with hairs pointing outwards to prevent the entry of unwanted creeping insects, like aphides, that might steal its nectar without pollinating the plant. Similarly, the petals of the lovely bogbean flower are so thick with hairs that insect-thieves are kept from its nectaries. The stem of chickweed, commonest of garden weeds, has two parallel lines of hairs that change their position alternately at each of the nodes or swellings. Their purpose is to conduct rain water collecting on each pair of leaves, down to the roots, for otherwise the abundant crowded growth of the plant would shelter its roots from any moisture. Hairs on the flower-stalk of the rose and hop produce a sticky substance that traps unwanted insect-climbers. In the sundew of our heaths the sticky hairs hold flies and other insects as on a fly-paper, their bodies forming the basic nitrogenous food of the sundew plant.

Most aquatic plants have air-cells to keep them erect. *Vallisneria*, the pond-weed so often used in the aquarium tank, has a spiral stem that straightens out until the plant reaches the surface. After fertilisation, the stalk reforms its spiral and the flower-head descends to the bottom where the seeds ripen in the mud. The water-lily also alters the length of its flower-stalk, but in this case the alteration is made in order to keep pace with a deepening river so that the flower is kept at the surface.

Bacteria are very useful in the soil, for they raise the nitrogen content, and nitrogen is essential to plant growth. Because of this we dig animal manure into the ground in winter so that it will rot and increase the bacteria content. We do not plant directly into fresh animal manure, however, because of the high ammonia content—it is this that causes the rank smell of fresh cow manure—but use well-rotted manure for planting.

The gardener must also lime his land especially near towns—in order to sweeten it and neutralize its acidity. Some plants, such as rhododendron bushes and potatoes, do not tolerate much lime, but others, such as carnations, like a lot. Sometimes we use stimulants, such as superphosphate of lime to encourage backward plants, or soot water to perfect the blooms.

The three elements, nitrogen, phosphorus, and potash are the most important chemical constituents required for plant life. Nitrogenous manures chiefly promote the growth of leaves and shoots and the green parts of the plant. They are thus useful tonics in spring after planting. Nitrate of soda, sulphate of ammonia, and soot enrich the nitrogen in the soil. Manures containing phosphorus improve the flowering and fruiting of plants, but because they are slower in action, they are applied earlier in the season, in the shape of bone-meal,

guano, basic slag, and superphosphate.

Manures containing potash affect the formation and transportation of the carbohydrates—the foodstuffs of plants. They can be given in the form of wood-ash, kainit, sulphate of potash, and other potash salts, large natural deposits of which occur in Germany.

Gardeners sometimes sterilise the soil to improve its fertility, for this kills the soil protozoa—the microscopic, single-celled animals that feed on bacteria. The bacteria spores survive and produce a fresh crop of bacteria.

The average farm soil is hungry for nitrogen, and much experiment and study has been devoted to this fertiliser. The knowledge that has been acquired about it in recent experiments has made it possible in effect to grow ten blades of grass where one grew before. This achievement is chiefly due to the magnificent research work of Sir Frederick Keeble at Jealott's Hill Research Station.

LARGEST AND SMALLEST PLANTS

The wonders of the plant-world range from the microscopic plants to the forest giants. On the one hand there is the tiny *Wolffia*, one of the three thousand plants of Florida. The size of a pinhead, it is the smallest of known flowering plants that float on the water. At the other end of the scale are the giant Douglas firs of Canada—the tallest of trees, they frequently exceed 100 ft. in height—and the Sequoia trees of California and Mexico, oldest and largest of trees. Some of the latter trees have stood for nearly 4,000 years and now have trunks over 100 ft. in circumference and one stands at a height of 450 ft. One of the biggest trees in the world is a cypress at Tule, in Mexico. It has a trunk-circumference of 154 ft., taking thirty men with outstretched arms to span its majestic Trunk.

In England, churchyard yews and ancient village oaks have frequently exceeded 1,000 years in age, and some are reputed to have reached 2,000 years. It is very doubtful, if an elm will exceed 300 years in age. Like so many of the trees of our countryside, the elm is an alien; but as female trees were planted on our farms, we do not find elms setting fertile fruits. They increase by vegetative reproduction or by underground suckers, a fact that explains why elm trees are nearly always found growing in clumps. Beech and ash trees also rarely exceed 300 years, but the lime may exceed 1,000. The larch reaches 570 years, the plane 750, the cedar 800, while the ivy may grow for 450 years.

ANATOMY OF THE TREE

We must remember that trees are not placed in a separate group of their own, but take their respective places amongst the 200,000 flowering plants of the world. Because the botanist classifies the higher plants by the structure of their flowers, the laburnum and acacia trees are placed in the same order as the gorse and the sweet pea, the broad bean and the lowly wayside rest-harrow, for all these have leguminous flowers.

We find that if we cut across a tree trunk we notice various definite rings and to these we referred in one of our early chapters. Outside the tree is a layer of waterproof bark, then a thin layer of food-conducting cells called the *Cortex*.

Deeper down is a hard layer of woody supporting cells (the *Endodermis*) enclosing the soft, sap-conducting cells that pump water from the roots under immense pressure. This water counteracts the loss due to the rapid transpiration of water from the leaves. These leaves are very numerous and vary with different kinds of trees. There are between 20 and 40,000,000 on a pine tree; 119,000 on a beech tree; 200,000 on a birch, and 7,000,000 on the elm.

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